“*Yamabico*” Autonomous Mobile Robots

User Programming Guide
Hardware & Software Implementation Notes
Reference

Version 1.5

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1. Hardware

The Yamabico robot is designed primarily for research and experimentation. Therefore, the software and hardware details are available to the user, for modification and revision at any time as required to suit the current purpose. With this in mind, the robot has been designed so as to simplify development, at the expense of power conservation, size, and overall cost.

The standard body of the robot is designed to be small to allow experimentation in a crowded laboratory, and to make handling easier. The purpose of the small robot is for the investigation and validation of navigational and sensing strategies. Hence, it uses wheels, and is designed for an indoor environment. This greatly simplifies research.

It is intended that the Hardware section of this document be read in conjunction with the circuit diagrams and the manufacturers data sheets for each individual IC. This information is gathered together into the Yamabico Hardware Manual [Yam95], a mix of English and Japanese documentation.

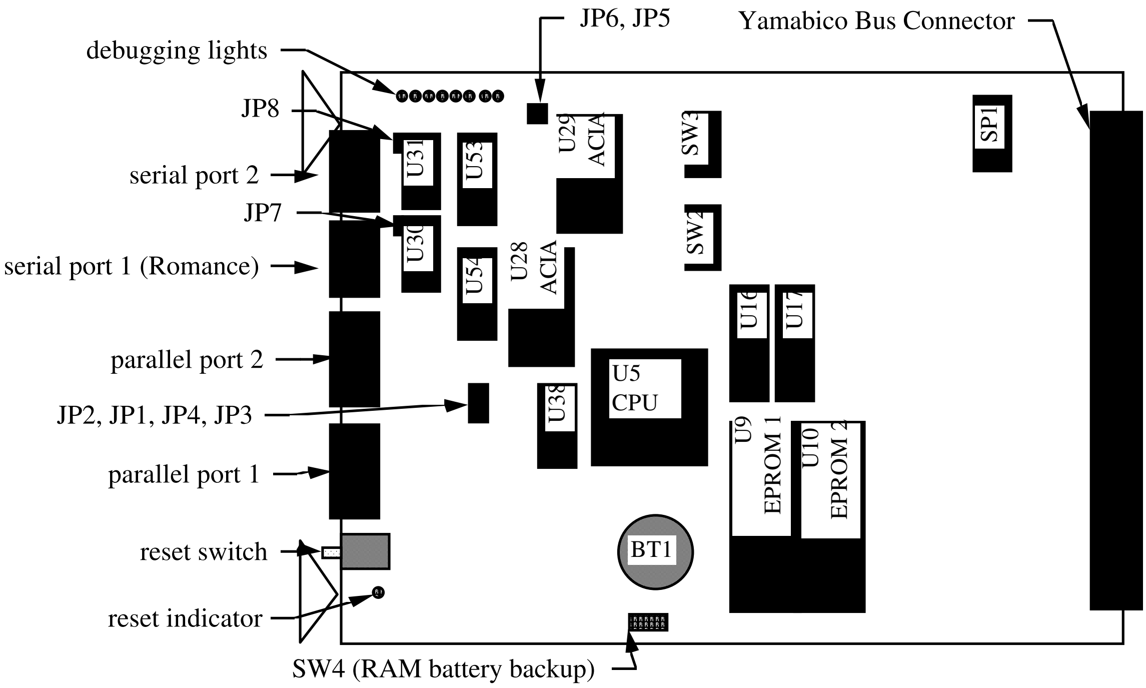
The aim of this documentation is to provide an understanding of how the hardware is designed to be used. Further information for programming can be found by inspection of the data sheets.

1.1 Architecture Overview

The robot's architecture is broken down into functional modules, according to function, to simplify research and development on individual components. For example, there is one module to control the ultrasonic sensing, and another module to control the motor drive system. All decision making is centralised, and is executed on a master module which is in control of the entire system. This is the behaviour level. This simplifies the process of upgrading and modifying individual function modules, because their operation and interactions are very clearly defined.

1.2 Modules

1.2.1 68000 Master Module mm-KEI



The 68000 master module board, showing the jumper leads and major chip positions.

The following descriptions are arranged according to which sheet of the circuit diagram they appear on.

1.2.1.1 CPU

The CPU is a 10MHz 68000, using a 16 bit data bus and a 24 bit address bus.

1.2.1.1.1 Reset Signal

The reset signal is activated by several sources:

- The reset switch, SW1
- Power-on reset circuit
- Power low condition, monitored by a MAX695
- Yamabico Bus reset line

1.2.1.2 Control

This diagram includes the memory address decoding, which is performed by two PALs, U16 & U17. The programming equations for the PALs are contained in the Yamabico Hardware Manual.

The 74HC161 counter, U18, re-maps the ROM to `0x000000` during the first four clock cycles after a reset. After that, it returns to its normal position in the memory space (`0xF80000~0xFBFFFF`). After startup, the binary outputs of U18 count to 4, which then disables the ENT and ENP inputs, thereby disabling further counting.

RAM is at the beginning of memory. The IO area is at the top of memory, with the ROM area just below it. Note that the VPA signal covers the whole IO range. This signal is designed to be returned to the 68000 CPU, to tell it that 6800 peripheral ICs are being used. This changes the bus mode of the CPU to emulate a 6800. Please see 68000 documentation for further information.

Note that the operating system is usually stored in ROM1, and that romance usually uses ACIA1. ROM2 may be used to store user programs if desired, but this is usually performed by battery backed RAM. Please see the MOSRA documentation for further details.

Device	Address Range
RAM1	`0x000000 ~ 0x03FFFF`
RAM2	`0x040000 ~ 0x07FFFF`
ROM1	`0xF80000 ~ 0xF9FFFF`
ROM2	`0xFA0000 ~ 0xFBFFFF`
VPA	`0xFC0000 ~ 0xFFFFFF`
ACIA1	`0xFC0000 ~ 0xFC00FF`
ACIA2	`0xFC0100 ~ 0xFC01FF`
PTM	`0xFC0200 ~ 0xFC02FF`
RTC	`0xFC0300 ~ 0xFC03FF`
PIA	`0xFC0400 ~ 0xFC04FF`
LED	`0xFC0500 ~ 0xFC05FF`
YBSEL	`0xFE0000 ~ 0xFFFFFF`
IOSEL	`0xFFFC00 ~ 0xFFFDFF`

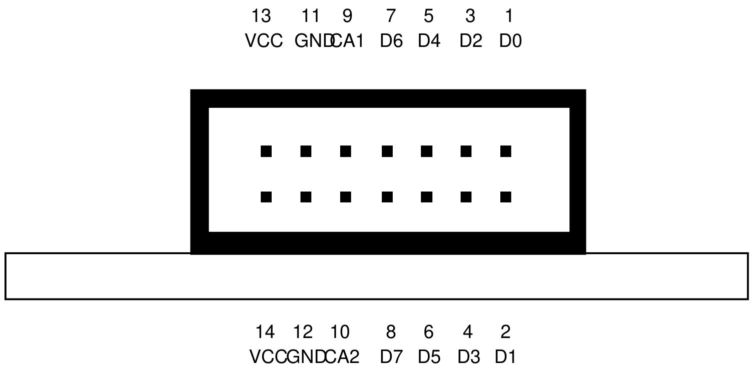
1.2.1.3 PIA — Parallel Interface Adaptor

The function of the parallel ports is controlled by the 6321 on this diagram. The two parallel ports can be operated on one direction each, which is selected by jumpers JP1-JP4. The table below shows how to select the position of the jumpers:

port 1	connect:
input	JP1
output	JP2

port 2	connect:
input	JP3
output	JP4

The ports are buffered for protection during experimentation. Port pinouts are shown below.



Connections for each of the parallel ports on the mm-KEI master module.

1.2.1.4 Memory

The 68000 master module supports 512kb of RAM, and 256kb of ROM. The CMOS RAM has a battery back up, so that when the robot is switched off the installed programs are retained.

The MOSRA operating system is contained in ROM. This contains the ROMANCE program, so when the board is first powered up it is possible to communicate with it via serial port 1.

1.2.1.5 Reset

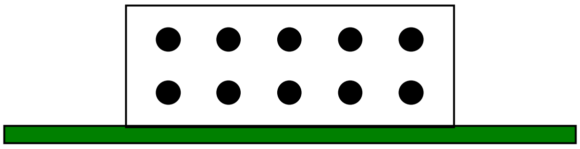
This circuit incorporates a MAX695, which monitors the +5V supply voltage and the battery backup voltage. When the +5V supply drops below specification, the RAM is powered from the backup battery, and the CPU is reset. The watchdog feature of the MAX695 is not used. Please refer to the MAX695 data in the Yamabico Hardware Manual for more information about this device.

The switch SW4 connects and disconnects the battery backup for the RAM. If the contents of the RAM are to be erased, or battery power is to be conserved (where the RAM contents are not important), this switch may be operated to the 0 position (as marked on the PCB). For normal operation, leave in the 1 position.

1.2.1.6 ACIA — Asynchronous Communications Interface Adaptor

There are two ACIA or serial ports on the master module mm-KEI. They can be used in either full RS-232 specification ±12V mode, or they can be configured for TTL levels only.

ACIA / ±12V version:



Connections for the RS-232 port in ±12V mode

This table shows the parts which must be installed on the PCB for ±12V operation. The part numbers for ports 1 and 2 are shown in the notation port1/port2.

Port 1	
U31 MAX232	Present
U53 74HC240	Absent
JP8	Disconnected

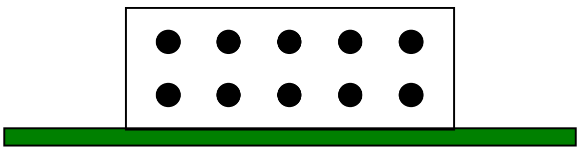
Port 2	
U31 MAX232	Present
U53 74HC240	Absent
JP8	Disconnected

The connections which must be made in the cable to connect to the ROMANCE port:

Yamabico Connector	Computer Connector
1 GND	GND
2 Tx	Rx
3 Rx	Tx
4 RTS	CTS
5 CTS	RTS
7 GND	GND

TTL / 0V-5V version:

It is suggested that this mode should be used if a radio modem in installed. This is because radio modems usually have TTL level I/O.



Connections for the serial port in TTL mode

Port 1	
U30 MAX232	Absent
U54 74HC240	Present
JP7	Linked

Port 2	
U31 MAX232	Absent
U53 74HC240	Present
JP8	Linked

In this case, it is not necessary to install the capacitors supporting the MAX232 chip.

If the port is to be used with the SEPCO (System Equipment Products) Wireless Modem, then a 74HC244 should be used instead of the 74HC240. This is because all the signal connections on the Wireless Modem are active low. A suitable cable is described in the table below:

Yamabico Connector	Wireless Modem Connector
1 GND	2 GND
5 VCC	1 VCC
6 *Rx	6 *RxD
7 GND	8 GND
8 *CTS	5 *CTS
9 *Tx	3 *TxD
10 *RTS	4 *RTS

In both cases, the ROMANCE program uses serial port 1.

Baud Rate Selection

This is performed by SW2 and SW3 for serial ports 1 and 2 respectively.

Switch Pattern 1 2 3 4 5 6	Speed (bps)
0 0 0 0 0 0	9600
0 0 0 1 0 0	4800
0 0 0 0 1 0	2400
0 0 0 1 1 0	1200
0 0 0 0 0 1	600
0 0 0 1 0 1	300

1.2.1.7 PTM/RTC/LED

PTM stands for Programmable Timer Module. It is connected to the interrupt line of the CPU. With suitable software, it can be used to generate a timer tick.

RTC stands for Real Time Clock. This chip is optional. It fits into the socket at U38.

The debugging LEDs are also on this diagram. They are written to for debugging purposes, mostly to give an indication of whether the CPU is running or not. They are switched off and on by JP5 and JP6:

Debug LEDs	Connect:

On	JP6
Off	JP5

1.2.1.8 Bus Buffer

At first glance, the function of the buffer appears to be superfluous. However, it is included to prevent total destruction of the module in the case of a mishap with the bus.

1.2.1.9 Yamabico Bus II

Details of this bus are in a document in the Yamabico Hardware Manual [Yam95]. The original Japanese document is '"Yamabico" no 68000 kanitsuite', by Iida.

1.2.1.10 Not on any diagram

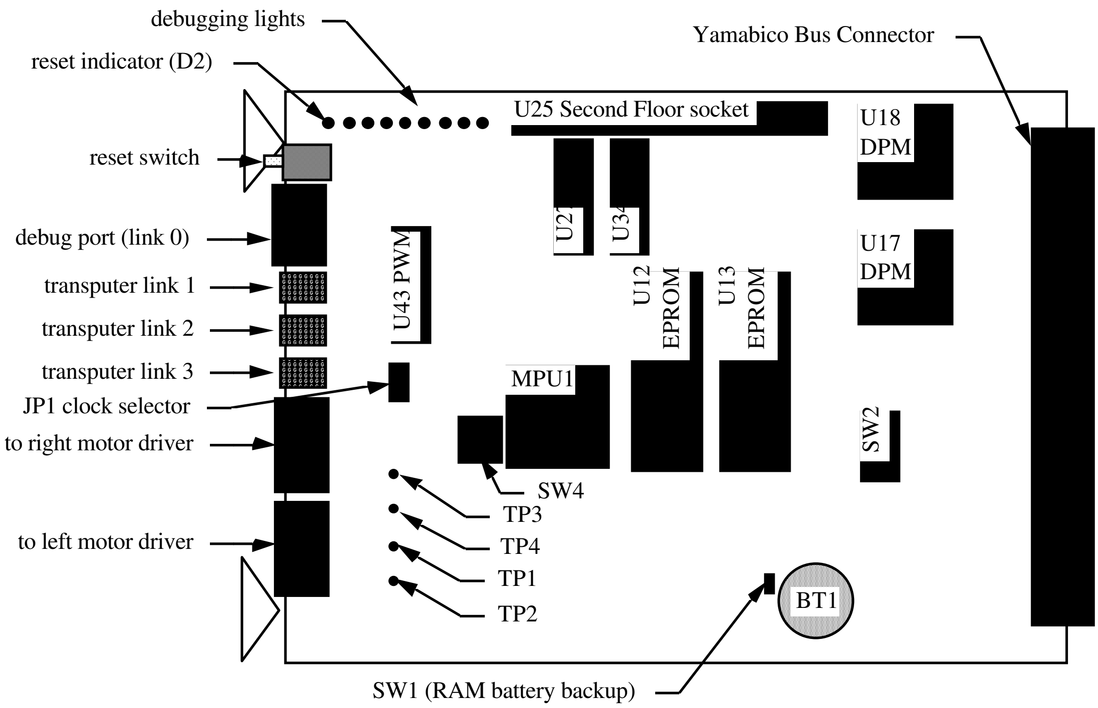
SP1: This position is a spare, for inserting a single IC during design revision and experimentation. None of the pins are connected to any other part of the pattern, except to the adjacent pads for patch wiring.

1.2.2 Transputer Locomotion Module

1.2.2.1 Introduction

The Locomotion module is designed to follow a given trajectory, using feedback based upon the shaft encoders. The general operation of the SPUR command language is documented in a paper by Shigeki Iida and Shin'ichi Yuta [Iida91].

The board operates as a digital PID controller for the motion of the robot. Please refer to [Iida91A] for further information on the control theory of the system.



1.2.2.2 MPU

The MPU in this module is an Inmos T805 Transputer. For more information on this processor, please refer to the manufacturer's documentation.

This diagram includes the reset button (SW3), and the reset indicator LED, D2. Note that this LED is positioned alongside the debugging LEDs.

The switches in SW4 are for configuring the CPU. Switches 1 to 3 control the speed of the transputer serial links. Switch 4 sets the boot from ROM or transputer link option. The effects of the switches are outlined in the following table:

Switch Number	CPU Pin label	Purpose	Action when On	Action when Off
1	Link Special	Select non-standard speed	non-standard speed = 20Mbits/sec	non-standard speed = 5Mbits/sec
2	Link0 Special	sets Link0 to non-standard speed.	non-standard speed	10Mbits/sec
3	Link123 Special	sets links 1 to 3 to non-standard speed.	non-standard speed	10Mbits/sec
4	Boot From ROM	Boot from external ROM or from Link	Boot from ROM	Boot from any link

The transputer link connections are also on this diagram. Link 0 is specially wired as a debug port. It includes the CPU status and control lines for hardware debugging. Please refer to the circuit diagrams for the pinout.

The other links are not used, and may be allocated as required.

1.2.2.3 Address Decoder

The address decoding is performed by two EP610 PALs. The address mapping is:

Signal Name	Address	Purpose
DPM	`0xFC0000`	Dual Port Memory
F2IO	`0xFC4000`	Second floor interface (using DTACK)
F2VPA	`0xFC8000`	Second floor interface (using Eclock)
ACIA	`0xFCC000`	ACIA device 6350
PTM	`0xFCC100`	PTM device 6340
PWM	`0xFCC200`	PWM generator
MODE_R	`0xFCC300`	right motor mode control register
MODE_L	`0xFCC400`	left motor mode control register
CNT_R	`0xFCC500`	right counter
CNT_L	`0xFCC600`	left counter
LED	`0xFCC700`	led
ADCON	`0xFC8000`	A/D converter

Note that F2IO and F2VPA have different purposes. If the peripheral being addressed is a 68000 class peripheral, then it should be selected by using DTACK. If it is a 6800 class peripheral, it should be addressed using F2VPA. In this way, the bus interfacing requirements are automatically taken care of.

1.2.2.4 Memory

The memory is battery-backed, so that programs may be stored while the robot is switched off, and cards can be removed from the robot frame.

1.2.2.5 Dual Port Memory (DPM)

The dual port memory is for communication with the master module, although this may be revised in future. It is proposed that transputer links may be used for this purpose.

The dual port memory consists of two chips, the IDT7130PLCC and IDT7140PLCC. Typically, the circuit is constructed using only the IDT7130 for both functions. The address of the DPM from the YBUS II side is selected by SW2, by using a comparator (U16) to detect when the upper address lines match the address selected with the switch. The usual position for the switches is:

123456

011101

On the TLOCO board, full 16 bit communication via Dual Port Memory is implemented.

1.2.2.6 Yamabico Bus Interface

The bus interface consists mostly of buffering for the signals which are used. The only exception is an interrupt line (VI5) used by the DPM to inform the master module that data is waiting to be read from the DPM. However, the current software implementation does not require this interrupt, and a common debugging technique in the Tsukuba University laboratory is to cut this interrupt line.

The buffering acts as an electrical firewall to guard against bus problems destroying the board.

1.2.2.7 PWM and Counter

This section contains the hardware which controls the motors, and monitors the shaft encoders.

The motor currents are controlled independently by two M66240 PWM generator chips. These operate under software control by the SPUR program. The feedback is provided by shaft encoders, whose outputs are monitored and counted by a pair of uPD4702/uPD4704 ICs per motor.

Header JP1 selects the input reference frequency to the PWM chip. The jumper should only be placed between one pair of pins at a time. The following table shows the frequency selected at each position:

Position	Frequency
1	10 MHz
2	5 MHz
3	2.5 MHz
4	1.25 MHz

If the jumper position is changed, then the software must be re-compiled.

1.2.2.8 LED

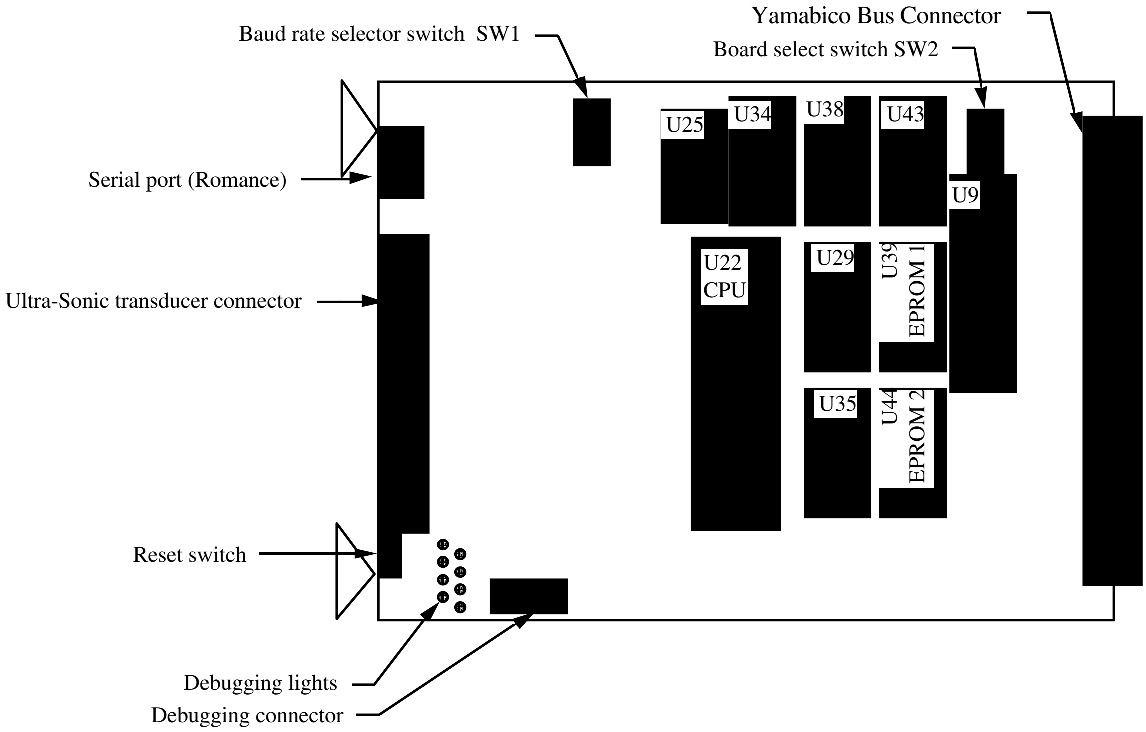
The LEDs are only used for debugging purposes. SPUR periodically writes to the LED register, which gives the user an indication that the board is running. This is most useful while performing hardware debugging.

1.2.2.9 Second Floor Interface (2F-I/F)

This is primarily designed for adding extra functionality to the TLOCO module. For example, the inverse pendulum control problem is solved by adding an extra part here, that interfaces the gyroscopic accelerometer to the TLOCO board, providing the extra feedback parameters required to control the posture angle of the robot.

The interface includes de-multiplexed address lines (2-16), select lines and clock, and multiplexed address-data lines (0-15). This allows extra hardware to be added.

1.2.3 Ultrasonic Sensor Module



Layout of the ultrasonic sensor module

The ultrasonic sensor module is designed to be used in conjunction with an ultrasonic driver circuit, such as HiSonic. It generates a transmit command signal, and measures the time until the 'receive' command is received from the ultrasonic driver circuit. The mode of operation is designed only for pulse-echo with threshold detection of the first echo. Further echoes are ignored. The method of determining the first echo is implemented in the ultrasonic driver circuit.

Note that when the HiSonic ultrasonic driver circuit is used, there is a modification to this module.[1]

1.2.3.1 CPU

The ultrasonic board uses a 10MHz 68000 CPU. The design is very similar to that for the mm-KEI master module.

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[1]The modification is to cut the wire from U11 pin 13 (MASK signal), and connect it to GND at pin 12 of U48.

1.2.3.2 Address Decoder

This diagram includes some simple address decoding, using binary decoding chips.

Also of interest is the ROM re-mapping circuitry, comprised of U54 and U16D. The ROM is at the beginning of memory (`0x000000`) just after system reset, but after the first four clock cycles, it is re-mapped to its normal position.

1.2.3.3 Memory

This board includes some RAM, which is not battery-backed, so it does not retain programs after switch-off. All necessary software is stored in ROM.

1.2.3.4 DPM

This is used for communication with the master module. This module only uses 8 bits for communication. The operation is very similar to the DPM in the TLOCO board in other respects.

Board selection is performed by decoding the upper address lines of the Yamabico bus. The decoding is simply a comparison with the outputs of a DIP switch, SW2. (The circuit diagram and the screen pattern on the board are different.)

The DPM can only be accessed from one side at an one time. The protocol which has been chosen is to allow the Yamabico bus to access the DPM while the E clock (on the Y-II bus) is high, and for the CPU on the peripheral module to access the DPM while the E clock is low. This is achieved by delaying acknowledgment of the memory access until the E clock is low.

1.2.3.5 PTM

The first PTM (Programmable Timer Module) is only used for software timing. This is because its only hardware connections are to the data bus, address bus, control lines and an interrupt line. The other PTMs are connected to the receive part of the circuitry. They count the time interval from the transmission of the pulse to the detection of the echo.

1.2.3.6 ACIA

This is for serial communication with a host computer, for debugging purposes. The baud rate is adjustable, as per the DIP switches in SW1. (Again, the circuit diagram and the screen pattern on the board is different.) For the allowable speeds, please refer to the data given in the 68000 Master module section.

The ACIA port is fully RS-232 compatible, having an on-board voltage converter chip to allow +/-10V signals to be generated and received.

1.2.3.7 Transmit

This section of the circuit sends out the signal to transmit to one of 12 ultrasonic modules. The board was designed for flexibility in the number of transmit/receive pairs to be used, so the same board can be used for both a standard 4 transducer set design and for a ring transducer set.

The transmitters to be used are directly selected by writing into the hardware register at TXPLUS. The bits are high to transmit, low to remain silent. The transmit pulse length is controlled by U7, a pre-settable counter. This counter counts from the set value to 0xFF before the transmit pulse is terminated. A one-shot timer, U11, ensures that the register at TXPLUS is cleared before the next transmit pulse.

The transmit pulse length, as discussed previously, is controlled by a pre-settable counter U7. This counter has double latches, the first of which store the count preset value. Hence, the starting count value only needs to be loaded once. All subsequent writes to TXPLUS cause the starting value to be loaded into the counting latches. The transmit pulse starts, and ends after 0xFF-start value clock pulses.

The transmit section also produces PR CONTROL signals for the receive section. These are used to prime flip-flops in the receive section.

1.2.3.8 Receive

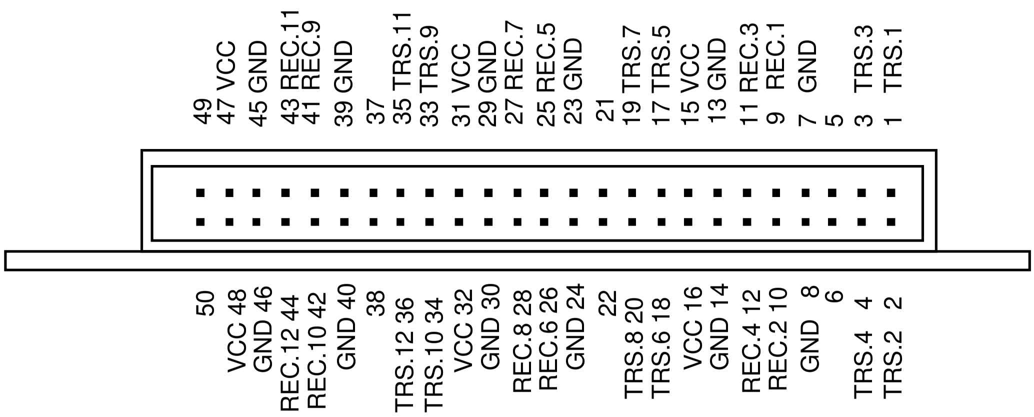
This diagram includes not only the receive circuitry, but also the register for the debug port, which is essentially a parallel port with LEDs and no handshaking.

The receive circuit consists firstly of two buffer ICs, U42 and U47. These are to guard against electrical malfunctions destroying the entire board.

The receive signals then pass to a bank of flip-flops, which are set to trigger or not trigger depending upon which channels transmitted. The output of each flip-flop is then OR'd with that of an adjacent channel, to reduce the total number of input channels to 6. These lines are then used to halt the associated PTM. The output is also directly readable to the CPU through address 3SB.

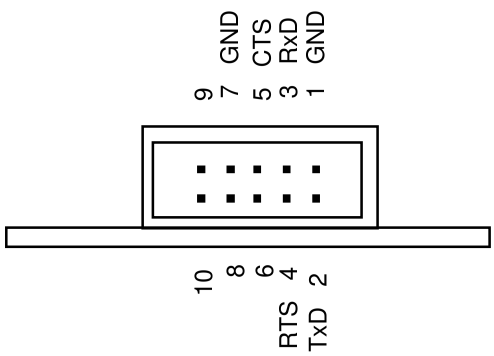
1.2.3.9 Connectors

The pinouts for the ultrasonic transducer connector are shown below. The connector is a 50 pin 0.1" spacing IDC type.



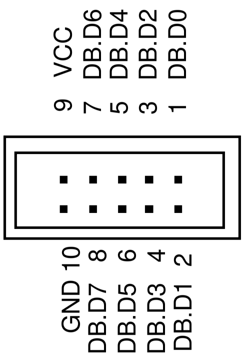
Ultrasonic transducer connector

The connections for the ACIA connector are shown below. Note that the connections are the same as for the serial ports on the 68000 master module, so the same cable may be used to connect the card to a host computer.



ACIA connector

The connections for the debug connector are shown below. Note that this port is not normally used.

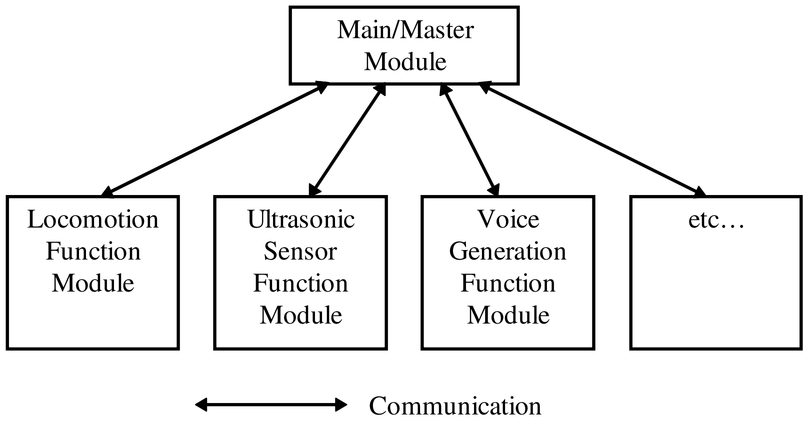


Debug connector

2. Software

2.1 Architecture Overview

The architecture of the software system mirrors that of the current hardware architecture of the robots. See the hardware section for the hardware architecture. The software functional architecture is as follows.



Software Architecture

The master module and each of the function modules executes a simple uni-processor operating system developed specifically for the Yamabico robots called *MOSRA*. The user program for high level control of the robot executes on the master module and conceptually initiates all communication over the Yamabico Bus (YBus) with the function modules. From the user's viewpoint the application programming interface (API) can be divided into MOSRA operating system calls, and calls specific to particular function modules. Each of the API's is detailed below.

Currently there are two implementations of the master module and of some of the function modules. The original designs employing a Motorola 68000 main processor and the newer INMOS T800 Transputer based boards. The following section on the Mosra operating system concerns only the 68000 based boards. From a software communications viewpoint the Transputer and 68000 function module boards are identical, as the communication protocol over the Yamabico Bus hides the specific hardware implementation.

2.1.1 Directory Tree

Below is a partial directory tree of the entire Yamabico project, with the exception of the Transputer software.

```
           |-doc----|-romance
           |
           |        |-compiler
           |-ground-|-install
           |        |-lib
           |        |-robol0
           |
           |        |-DPM
           |        |-HiSonic
   ys-kit- |        |-ISSUE
           |        |-SONic
           |        |-Spur
           |-module-|-Spur-16
           |        |-Spur-telop
           |        |-US12
           |        |-US_ring
           |        |-USwithPL
           |        |-Voice
           |
           |-mosra
```

The directory contents are as follows:

- doc - Documentation[2]
- ground - The ground software - Compilers, Simulators, etc.
- module - Directories for each function module developed
- mosra - The MOSRA OS

Ground

The *ground* directory contains:

- compiler - The **`mcc`** compiler driver and **`ml68`** linker source
- install - Scripts for making OS/9 libs and includes
- lib - Template headers and makefiles
- robol0 - **`roboc`** - old driver for *Robol/0* compilation

Module

The *module* directory contains a subdirectory for the software of each of the developed function module boards. These function modules are:

- HiSonic - The HiSonic UltraSonic module (Newer than SONic)
- ISSUE - ISeye Software United Environment
- SONic - The UltraSonic module
- Spur - The Spur locomotion module (8 bit integer version)

[2]Documentation is not available for most software

- Spur-16 - The Spur locomotion module (16 bit integer version)
- Spur-telop - A version of Spur for TeleOperation
- US12 - US eye *(for Yamabico type 10)*
- US_ring - UltraSonic ring software
- Voice - The Voice Synthesiser/Generator software (Japanese)
- DPM[3] - Source for Dual Port Memory and SIP[4] functions

2.2 MOSRA

MOSRA[5] is a simple operating system designed specifically to execute on Yamabico robots. It has been designed to be object module compatible with the OS-9 operating system so that existing OS-9 targeted compilers may be utilised.

2.2.1 Features

The major features of MOSRA are:

- Process management - cooperative multitasking
- Interrupt handling
- Exception handling
- Memory module management (single address space for all processes)
- Memory allocation management
- Interprocess communication (using shared memory)

The MOSRA API calls will be detailed in terms of these functional divisions.

[3]Refer to the "*Yamabico Bus II*" section in the Yamabico *Hardware Folder* for a detailed description of the DPM hardware and protocol used for communication over the Yamabico Bus II.

[4]SIP - State Information Panel (data structure for exchange of information between modules via DPM). Sometimes also referred to as State Information Monitoring Panel (SIMP)

[5]MOSRA - The cooperative multitasking Operating System that runs on Yamabico robots.

2.2.2 MOSRA API

2.2.2.1 Memory Allocation

Low level memory allocation in MOSRA is managed using these memory allocation calls. Each allocation should be matched by a corresponding deallocation (**`mfree`**) to return the memory back to the free memory pool once it is no longer required. Memory is allocated from a global free memory pool.

API Calls

`char* malloc(int size)`

Description:

Allocates some memory of at least the requested size if enough memory is available.

Parameters:

`size` The size in bytes of the memory required.

Return:

The address of at least *size* bytes of memory, or 0 if not enough memory is free.

`mfree(char* address)`

Description:

Frees the specified pre-allocated memory, releasing it back into the free memory pool. No check is made to ensure memory has been allocated at the address. DO NOT free unallocated memory. This call cannot be used to directly free MOSRA memory modules.

Parameters:

`address` The address of previously allocated memory.

Return:

`void`

Example

```
main()
{
     char *Mem_for_integers;

     Mem_for_integers = malloc(100*sizeof(int)); // allocate memory for 100
int's
     if (Mem_for_integers == 0) {
          write_cons("Not enough memory.");
          death();  // kill this process
     }

     // Use the memory
     ...

     mfree(Mem_for_integers);
}
```

2.2.2.2 Memory Modules

MOSRA handles the main CPU memory in terms of *Memory Modules*. A memory module is a region of memory delimited by a special header section that identifies memory modules and provide information such as a name. The memory module format matches that of OS-9. The format is detailed in the *MOSRA Implementation* section below. Memory modules can be further divided into *execution modules* and *data modules*. Both share common header information. The modules are generated by the OS-9 targeted **Microware C** compiler.

API Calls

`int ismod(MOD_DATA* m_adr)`

Description:

Tests if the supplied address points to a memory module.

Parameters:

`m_adr` Address of memory module structure

Return:

Returns **`TRUE`**[6] if the supplied address points to a memory module, **`FALSE`** otherwise.

[6] FALSE == 0, TRUE == non zero (usually 1)

`MOD_DATA* make_mod(char* mname, int size)`

Description:

Request the creation of a new memory module of the specified size and with the given name. Uses **`malloc()`**, see memory allocation API. You should call **`crcgen()`** after this to calculate the CRC check. MOSRA will not recognise the memory module by name in any memory module calls that take a name parameter until you register the module in the directory by calling **`regmod()`**.

Parameters:

`mname`	C character string name for the new module
`msize`	The requested size in bytes

Return:

Returns the address of the new module, or **`0`** if an error occurred. An error can be caused by lack of memory.

`crcgen(MOD_DATA* m_addr)`

Description:

Calculates and fills in the CRC (Cyclic Redundancy Check) field of the specified memory module. MOSRA will only recognise memory modules with correct CRC's for some memory module operations.

Parameters:

`m_addr`	Address of a pre-allocated memory module (created with **`make_mod()`**).

Return:

`void`

MOD_DATA* get_mod(char* mname)

Description:

Finds the address of a memory module by name, if a module with the specified name exists.

Parameters:

mname C string name of module to find the address of.

Return:

The address of a module with the given name, **0** if no such named module exists.

---

int regmod(MOD_DATA* m_addr)

Description:

Registers the specified module with MOSRA.

Parameters:

m_addr Address of pre-allocated and CRC checked memory module.

Return:

TRUE if registered OK, **FALSE** otherwise.

---

int delmod(MOD_DATA* m_addr)

Description:

Unregister the specified memory module with MOSRA and delete it, hence freeing it's memory for use.

Parameters:

m_addr Address of memory module to unregister and deallocate.

Return:

TRUE if OK, **FALSE** if error.

Example

```
#include <mosra/system.h>
#include <mosra/data.h>

main()
{
     int b;

     // Duplicate the startup module (standard module executed on MOSRA
boot)

     // First find the "startup" module
     //      NB: Actually the startup module is an executable module
(EXEC_MOD),
     //       but we can just treat it as a DATA_MOD for copying it.  The
     //           memory module functions are also prototyped as returning
MOD_DATA
     //       so we save casting.

     MOD_DATA* newmod;
     MOD_DATA* startmod = get_mod("startup");
     if (startmod == NIL) {
          write_cons("No startup module! - oops");
          death();
     }

     // Create new module in memory
     newmod = make_mod("start_copy", startmod->mh_size);  // same size

     if (newmod == NIL) {
          write_cons("no memory for new module");
          death();
     }

     // Copy the startup module's data into the new module's data
     //  (see implementation section for the MOD_DATA structure definition)
     for(b = 0; b < startmod->mh_dsize; b++)
          *(newmod + newmod->mh_data + b) = *(startmod + startmod->mh_data +
b);

     // Update new module's CRC
     crcgen(newmod);

     // And register it in the module directory
     if ( regmod(newmod) == FALSE) {
          write_cons("error registering module");
          death();
     }

     // Now we could use fork() to start executing our new module if we
wished.
     ...

     // Done with it, now unregister and delete the module
     delmod(newmod);     // This also unregisterd the module in the
directory
}
```

2.2.2.3 Process Control

MOSRA process management is very simple. Multitasking is cooperative so processes must voluntarily relinquish the processor to other processes. A process can be in any of three states, *RUN, WAIT or MESW*. A process in the *RUN* state is ready to run and may be executing. A process in the *WAIT* state is blocked waiting for some event, like a **`wakeup()`** call from another process. A process in the *MESW* state is waiting for an IPC[7] message from either a specific source or from any source. Once such a message has been received the process will go into the *RUN* state.

API Calls

`int mfork(char* mname, int pid, int priority)`

Description:

Creates a new process that executes the code in the execution memory module specified by name. The process will have the PID (Process Identifier) that was supplied, unless it was already in use. If 0 is supplied as a PID, MOSRA chooses a PID.

Parameters:

`mname`	C String name specifying the execution module for the process.
`pid`	PID to use, or 0 if MOSRA may choose a PID.
`priority`	The required priority of the process in the range 1-256. The larger the number the higher the priority. Default is 9.

Return:

The PID of the created process. This is as supplied or in the case 0 was supplied the PID MOSRA has chosen. If the PID supplied was already in use, the call fails and 0 is returned. Returns the named module doesn't exist in the module directory.

`int pcreate(MOD_EXEC* mod_address, int pid,int priority)`

Description:

Creates a new process that executes the code in the execution memory module specified by **`mod_address`**. The process will have the PID (Process Identifier) that was supplied, unless it was already in use. If 0 is supplied as a PID, MOSRA chooses a PID.

[7] IPC - Inter Process Communication

The function is identical to **`mfork()`** except the executable module is supplied by address rather than by name.

Parameters:

`mod_address`	Address specifying the execution module for the process.
`pid`	PID to use, or 0 if MOSRA may choose a PID.
`priority`	The required priority of the process in the range 1-256. The larger the number the higher the priority. Default is 9.

Return:

The PID of the created process. This is as supplied or in the case 0 was supplied the PID MOSRA has chosen. If the PID supplied was already in use, 0 is returned.

`int tfork(void* start_pc, int pid, int priority)`[8]

Description:

Creates a new thread that shares the same code and data as the parent thread or process. A thread is just a process that shares it's module and data area. Execution will start at the address specified, usually a C function that must never return, but should end with **`death()`**. The thread will have the PID (Process Identifier) that was supplied, unless it was already in use. If 0 is supplied as a PID, MOSRA chooses a PID.

Note that only the first process started for a given code module (the parent) will deallocate the static data area upon exit. Hence ***all*** child threads should terminate ***before*** their parent.

Parameters:

`start_pc`	Address of the execution entry point (e.g. a C function - which is a pointer to it's code).
`pid`	PID to use, or 0 if MOSRA may choose a PID.
`priority`	The required priority of the process in the range 1-256. The larger the number the higher the priority. Default is 9.

Return:

The PID of the created process. This is as supplied or in the case 0 was supplied the PID MOSRA has chosen. If the PID supplied was already in use, the call fails and 0 is returned. Returns the named module doesn't exist in the module directory.

---

[8] Threads are only available in some versions of the MOSRA kernel. They were added at Wollongong University.

`death()`

Description:

This function kills the calling process. Hence it never returns, since the calling function will never be re-scheduled. The calling process's process descriptor is unlinked from the active process list and the static data and stack is deallocated[9].

Parameters:

None.

Return:

Never returns.

`sleep()`

Description:

This function causes the calling process to switch into the *WAIT* state, hence relinquishing the CPU to the next process in the *RUN* state. If no other processes are ready to execute (in the *RUN* state) the CPU will halt until a process becomes ready to run. Interrupts will continue to be processed. The process will remain in the *WAIT* state until explicitly put into the *RUN* state by a call to **`wakeup()`**. The **`sleep()`** and **`wakeup()`** functions together allow a user defined scheduling to be imposed on processes[10].

Parameters:

None.

Return:

void.

[9] Only parent processes deallocate the static data area, not child threads. Hence all children should terminate before their ultimate parent process.

[10] This is mostly useful when using processes executing in cooperative scheduled mode of MOSRA. Later versions of MOSRA have the option of executing processes under a pre-emptive multitasking schedular.

`int wakeup(int pid)`

Description:

Changes the state of the process with PID **`pid`** to *RUN*, and immediately transfers control to this process. The process must have been previously in the *WAIT* state (it must have called **`sleep()`**), or the *RUN* state (in which case control is just passed).

Parameters:

`pid`	The Process ID (PID) of the process to begin execution.

Return:

`TRUE` if OK, **`FALSE`** if error (e.g. no process with the given PID exists), in which case the call has no effect.

`int getpid()`

Description:

Get the Process ID (PID) of the current process (the caller).

Parameters:

None.

Return:

The PID of the caller.

`char* get_work()`

Description:

This call is not normally required by user/application code. It gives the address of the static data area. The data area is location of the static variables and C stack[11].

Parameters:

None.

Return:

Address of the data area of the caller process.

[11] In later versions of MOSRA that support Threads, the static area and stack are no longer allocated together. This is because threads share the same data area but each have their own stack.

Example

```
#include <mosra/system.h>
#include <mosra/data.h>

// proc1 main
main()
{
     // Assume we have an executable memory module in memory called
     //  "proc2".  Start this as a new process.

     int proc2pid;
     proc2pid = mfork("proc2", 0, 9);

     while (more_work_to_do) {
          // do some work

          // relinquish control of CPU (to proc2)
          sleep();
     }
     death();  // no more work to do so kill ourself!

}

// proc2 main
main()
{
     int proc1pid;  // must find out proc1's PID.  proc1 will need to send
us a
                    //  message containing it's PID
     ...
     while (more work to do) {
          // do some work

          // Throw control back to proc1
          wakeup(proc1pid);
     }
     death();  // no more work to do so kill ourself!
}
```

2.2.2.4 Interprocess Communication (IPC)

Interprocess communication in MOSRA is modelled on message passing. The current implementation is very efficient because it uses pointer passing, possible since all processes share a common address space.

Types

This type should be included as the first member of a user defined message type, or the user can define message structure that duplicates these fields as the first three. The user is responsible for allocation of the message. The usual convention is for the sender to allocate the message space and the receiver deallocates it. For this reason it is not advisable to use **`static`**ally declared message structures.

```
/*
 * data structure for message
 */
typedef struct _messt {
          struct _messt *ms_next;        /* pointer to the next message */
          int            ms_leng;        /* message length */
          SHORT          ms_scid;        /* message source ID */

          /* user/application message data goes here */

} MESST;
```

Example

```
// User defined message for commands

typedef struct _mymessg {
          MESST messg;
          int       command;
          int       x,y,th;
} COMMAND_MESG;
```

API Calls

`int send_mess(int pid, char* mes_p)`

Description:

Send a message to a specified process. By convention the sender allocates memory for a message and the receiver deallocates the memory. Hence do not free the memory for messages you send and do not declare a message as a static or stack variable (or it will be deallocated by the program automatically).

Parameters:

`pid`	The Process ID of the destination process.
`mes_p`	The address of the message to send.

Return:

`TRUE` if message sent OK, **`FALSE`** if error (e.g. invalid PID)

`void* recv_mess(int pid)`

Description:

Receive a message from the specified source process, or from any process. The process will **`sleep()`** until a message is available. By convention the receiver always deallocates any received messages.

Parameters:

`pid`	The Process ID of the source process, or 0 to specify any source.

Return:

The address of the received message structure.

`int test_mess(int pid)`

Description:

Because a process may block (state *MESW* - Message Wait) if no messages are available when using **`recv_mess()`**, this function allows the caller to test if any messages are waiting to be received. The parameter has the same meaning as for **`recv_mess()`**. If a message is waiting, the next call to **`recv_mess()`** with the same argument is guaranteed to return a message without blocking.

Parameters:

`pid`	The Process ID of the source process, or 0 to specify any source.

Return:

`TRUE` if at least one message is waiting, **`FALSE`** otherwise.

Example

```
#include <mosra/system.h>
#include <mosra/data.h>

main()
{
      // Assume message definition in example above, and a process exists
with PID
      //  childpid.
      ...

      COMMAND_MESG *mycommand, *reply;
      MESST *m;

      // Construct a command message and send it to the child process
      mycommand = malloc(sizeof(COMMAND_MESG));  // child will mfree
      mycommand->command = COMMAND_CODE_1;
      mycommand->x = 0;
      mycommand->y = 50;
      mycommand->th = 90;
      send_mess(childpid, mycommand);  // send message to child process

      // Now wait for a reply
      reply = recv_mess(childpid);

      // Now loop and process any messages we get from any other process
      for(;;) {
            if ( test_mess(0) == TRUE ) {  // if a message is waiting
                  m = recv_mess(0);  // get the message
                  ... process incoming message ...
                  mfree(m);   // as reciever it's our responsibility to mfree
the msg
            }

            ... do work ...

      }
}
```

2.2.2.5 Interrupt & Exception Handling

MOSRA implements a set of system calls for managing interrupt handlers (service routines) for CPU interrupts and for locking out interrupts during critical code sections. MOSRA maintains a separate handler chain for each CPU interrupt level. Some of the calls described below take parameters of the following Interrupt Request Table type.

```
/*
 * interrupt table structure
 */
typedef struct _irqtbl{
          char           *iq_poll;       /* polling device address */
          char           iq_mask;        /* mask byte */
          char           iq_flip;        /* flip byte */
          LONG           (*iq_serv)(),   /* interrupt service address */
                         iq_static;      /* static storage address */
          SHORT          iq_prio;        /* interrupt priority */
          struct _irqtbl *iq_next;       /* pointer for nextt irq table */
} IRQTBL;
```

This structure is used when installing a new interrupt handler for a specific CPU interrupt level. The interrupt handling routine is entered into the **iq_serv** field. As there may be several devices that trigger the same level interrupt to the CPU, MOSRA will only activate the service routine if the byte at the address specified by **iq_poll** AND'ed with the mask **iq_mask** and exclusive OR'ed with **iq_flip** is non-zero. That is, if

```
(*iq_poll & (iq_mask ^ iq_flip)) & $FF != $00
```

Before the interrupt routine is activated, register **A6** is loaded with the value in **iq_static** which points to the process's static data area. The code generated by the OS/9 compiler uses indirect addressing via the A6 register for access to static data. The **iq_prio** specifies the required priority of the handler. This determines the order in which handlers in the chain are called. The **iq_next** field is used by MOSRA internally for chaining and should not be used by user code. Note that the functions that install and remove interrupts modify the interrupt handler chain for the specified level, so you should ensure that interrupts to the CPU of this level do not occur during the function call (i.e. disable them).

API Calls

`int irqtbl(int level, IRQTBL* table)`

Description:

This function installs a new interrupt service routine (handler) as specified by the **`table`** structure as described above, into the interrupt level **`level`** chain.

Parameters:

`level`	The CPU interrupt level [0..7]
`table`	The IRQTBL pointer as described above.

Return:

TRUE for success, FALSE for failure (level was > 7).

`int irqdel(int level, IRQTBL* table)`

Description:

This routine removes the specified IRQ table from the chain. The **`table`** must be the same pointer as passed to **`irqtbl()`** for this **`level`**.

Parameters:

`level`	The CPU interrupt level [0..7]
`table`	The IRQTBL pointer as passed to **`irqtbl()`**.

Return:

TRUE is removed successfully, FALSE if not found in the **`level`** chain.

`int irqctl(int pid, int level)`

Description:

This functions sets the CPU interrupt priority mask of the specified process as defined in the Status Register (SR) bits 10-12.

Parameters:

`pid`	Process IDentifier of process whose priority mask is to be modified. If **`pid`** is 0 the priority mask of all processes will be changed.
`level`	The new mask level.

Return:

TRUE is successful, FALSE if the process is not found.

`exsect()`

Description:

This function masks all interrupts while the current process is executing. It also retains the current interrupt mask for the process so it may be restored by **`exend()`**. The **`exsect()`**...**`exend()`** pair can be used when an exclusion section is required in code.

Parameters:

None.

Return:

Void.

`exend()`

Description:

This function returns the current process interrupt mask to the value previous to the **`exsect()`** call. **`exend()`** must only be called after **`exsect()`**. It may be used to end a critical section of code.

Parameters:

None.

Return:

Void.

`irqset(int level)`

Description:

This function sets the CPU interrupt priority mask of the current process as defined in the Status Register (SR) bits 10-12. The current level is retained for restoration upon a call to **`irqrst()`**.

Parameters:

`level` The new interrupt priority mask.

Return:

Void.

`irqrst()`

Description:

This function restores the CPU interrupt priority mask of the current process to the value previous to the last call to **`irqset()`**.

Parameters:

None.

Return:

Void.

2.2.2.6 Semaphores

Semaphores are a synchronisation primitive commonly used to manage mutual exclusion of resources shared between multiple processes. They can also be used as a convenient and efficient signalling mechanism. The semaphores implemented MOSRA[12] are binary semaphores, not counting semaphores. The API, as described here, is very similar to the VxWorks OS semaphore API.

Semaphores can be used to protect access to data shared between multiple threads or processes. Note that if processes are only being scheduled cooperatively, semaphores need not be used to protect shared data since no pre-emption can take place unless explicitly programmed

[12] Semaphores were developed for a version of MOSRA at the University of Wollongong. They are most useful when using pre-emptive scheduling as developed jointly by the Tsukuba and Wollongong Laboratories.

(via calls that relinquish the CPU, like **`sleep()`**, **`send_mess()`**, etc.). They may be useful, however, for sharing data between processes and interrupt routines.

`Semaphore semcreate()`

Description:

This function creates a new semaphore for use and returns it's semaphore ID. The ID is subsequently used by all other semaphore API calls for identification. Every call to **`semcreate()`** should be matched with a call to **`semdelete()`** to free the semaphore when no longer needed. There are only a finite number of semaphores in the system.

Parameters: None.

Return:

The new semaphore ID, or -1 in case of error (semaphore table is full).

`int semdelete(Semaphore sem)`

Description:

This deallocates the specified semaphore so it may be reused by new calls to **`semcreate()`**. It is safe to call this with a semaphore that has already been deleted, but is bad practice, since the semaphore may have been re-cycled in another call to **`semcreate()`**. It is also good practice for the calling process to own the semaphore being deleted, in case another process is blocked waiting for it, in which case it will block forever. It is not necessary that the caller be the same process that created the semaphore.

Parameters:

`sem`	The semaphore ID of the semaphore to delete, as returned by **`semcreate()`**.

Return:

TRUE if the semaphore had been created and was successfully deleted, FALSE if the semaphore had not been previously created, in which case the call has no effect.

`int semtake(Semaphore sem, int blockingmode)`

Description:

Attempt to take (own) the semaphore specified (e.g. own the resource represented by the semaphore).

Parameters:

`sem`	The semaphore ID of the semaphore to attempt to take. Must be a valid ID as returned by **`semcreate()`**.
`blockingmode`	One of **`BLOCKING`** or **`NONBLOCKING`**. If **`BLOCKING`**, the calling process will block (in state **`SEMW`**) until the semaphore becomes available (the owner calls **`semgive()`**). If **`NONBLOCKING`** the call will return immediately and the return code will indicate if the semaphore could be owned or not.

Return:

FALSE if the semaphore was not available (already taken or not valid), TRUE if taken successfully. If **`BLOCKING`** mode, always returns TRUE after taking (unless invalid).

`int semgive(Semaphore sem)`

Description:

Attempt to give back (disown[13]) the semaphore specified (e.g. disown the resource represented by the semaphore). The semaphore must have already been taken (by any process) or the call has no effect. If one or more other processes (or threads) are blocked waiting to take the semaphore, execution control of the CPU will immediately be passed to one of the waiting processes (which will be unblocked as it's blocking call to **`semtake()`** returns).

Parameters:

`sem`	The semaphore ID of the semaphore to give. Must be a valid ID as returned by **`semcreate()`**.

[13] Semaphores are not actually owned by any particular thread. If used for mutual exclusion it is usually best to conceptually think of them in this way (as being owned by the thread that calls **`semtake()`**). Hence calls to **`semtake()`** are usually matched with corresponding calls to **`semgive()`** ***by the same thread*** (although this is not necessary). If used for signalling purposes this is usually not the case.

Return:

TRUE if given successfully (the CPU may have been lost to another thread before the call returns), or FALSE if the semaphore was not taken or not valid.

Example

```
#include <mosra/system.h>
#include <mosra/data.h>


// shared data
LinkedList list;

// semaphore to protect access to list
Semaphore listsem;

thread_proc()
{
     while (my_work_do_do) {
         … do work …

         // access list
         semtake(listsem, BLOCKING);
         … manipluate list …
         semgive(listsem);

         … do more work …
     }


     death();  // no more work to do so kill ourself!

}


main()
{
     listsem = semcreate();    // create this before starting thread_proc()
                               //  because tfork() (and mfork()) transfer
                               //  execution immediately to the new process,
                               //  hence it may try to semtake() on an
                               //  invalid semaphore.

     // start a new thread for this module (main is the parent process)
     int childPID = tfork(thread_proc, 0, 0x70);


     while (work_to_do) {
         … do work …

         // need to access list
         semtake(listsem, BLOCKING);  // wait until thread_proc() isn't
                                      //  using list (if it was)
         … manipluate list …
         semgive(listsem);

         … do more work …
     }
     semtake(listsem, BLOCKING); // don't just destroy it
                                 //   from under thread_proc()'s nose!
     semdelete(listsem);

     death();  // no more work to do so kill ourself!
}
```

2.2.3 MOSRA Implementation

This section assumes familiarity with the MOSRA API. All type definitions listed in the *Types* sections to follow are from the header file **`ys-kit/mosra/defs/mosra/data.h`**.

2.2.3.1 System Initialisation & the Global System Table

MOSRA is activated by a boot program.(**`boot.c/boot.a`**) As the power is supplied or a reset button is pushed, the boot program activates, and searches for the MOSRA kernel in RAM and ROM. After MOSRA is found, MOSRA can control the system.

Order of Initialisation (**`main.c`**):

1. Initialisation of 68000 vector table
2. Initialisation of MOSRA system table
3. Search and registration of memory modules
4. Drawing up free memory links
5. Registration of MOSRA as process
6. Activating startup module

Only startup is activated by MOSRA. All other necessary processes are activated by startup.

Types

This structure is the global system table. It is always located at address **`0`**.

```
typedef struct _sysglob {
    LONG      (*D_VECT[VCTSIZE])(); /* exception vectors */
    IRQTBL    *D_IRQT[IRQTSIZE];    /* irq managemant table link top */
    PDSC      *D_APROC;      /* active process link top */
    FMEM      *D_FREEM;      /* free memory link top (size = 0) */
    LONG      D_RAMTOP,      /* RAM area top ( lowest addr ) */
              D_RAMEND,      /* RAM area end ( highest addr ) */
              D_ROMTOP,      /* ROM area top ( lowest addr ) */
              D_ROMEND,      /* ROM area end ( highest addr ) */
              D_MODE;        /* Round robin mode or cooperative */
    PDSC      *D_RRLIST;     /* circular list of processes for round robin */
    SEMTBL    *D_SEMT;       /* Table of active semaphores */
    LONG      D_free[47];         /* free area ( unused ) */
    PDSC      *D_PTBL[PTBLSIZE];   /* process descriptor directory */
    MOD_EXEC *D_MDIR[MDIRSIZE];   /* module directory */
    LONG      _sp_svc[STACKSIZE],  /* stack area for system servicecall */
              _sp_irq[STACKSIZE];  /* stack area for interrupt */
} SYSGLOB;
```

The fields in this structure are mostly self explanatory. As **`SYSGLOB`** is always located at address **`0`**, the **`D_VECT`** array maps directly onto the 68000's exception vector area, and hence provides a convenient method for accessing it. The **`D_IRQT`** is an array of linked lists of interrupt handlers, one for each processor interrupt level. All processes that are currently active are linked in priority order from **`D_APROC`** as well as being accessible from the array **`D_PTBL`** indexed by process ID. The **`D_RAMTOP/END`** and **`D_ROMTOP/END`** fields give the address range of RAM and ROM respectively. **D_MDIR** is an array of pointers to memory modules, **_sp_svc** and **_sp_irq** are stack areas used during kernel and interrupt execution respectively. In versions of MOSRA that support pre-emptive multitask scheduling, the **D_MODE** and **D_RRLIST** flag the scheduling mode and store the list of processes being round-robin scheduled respectively (the remaining processes not on this list are scheduled cooperatively as in older versions). The **D_SEMT** points to a semaphore table for managing semaphores.

2.2.3.2 Memory Allocation

Types

```
/*
 * data structure for free memory link
 */
typedef struct _fmem{
          int            fm_size;        /* memory block size */
          struct _fmem   *fm_next;       /* memory link */
} FMEM;
```

This is the node type of a linked list of free areas of memory starting at the address of the node and extending for **fm_size** bytes. When memory is freed using **mfree()**, adjacent areas of free memory are coalesced into a contiguous area.

2.2.3.3 Memory Modules

Types

A Memory Module (MM) consists of :

- Common header
- Header for execution module / Header for data module
- Machine word code
- Initialising information
- CRC code

The size of the data area and stack area, offset to initialising information of the data area and text area, are recorded in the header for the execution module. MOSRA initialises processes when created with **fork()** on the basis of this information.

```
/*
 * header structure of execution module
 */
typedef struct mod_exec{
          SHORT  mh_sync,              /*  sync  code(4afc)  (Magic#  for  MM
identification) */
                 mh_sysrev;     /* system revision */
          LONG   mh_size,       /* module size */
                 mh_owner,      /* owner id */
                 mh_name;       /* module name */
          SHORT mh_undef[15],   /* unused in mosra */
                 mh_parity;     /* header parity code */
          LONG   mh_exec,       /* offset to execution entry */
                 mh_ecept,      /* offset to exception entry */
                 mh_mem,        /* data area rquirement */
                 mh_stack,      /* stack size */
                 mh_idata,      /* offset to initialized data */
                 mh_irefs;      /* offset to data reference lists */
} MOD_EXEC;
```

This structure is an OS/9 format object module header. The object modules produced by the compiler for the Yamabico robots produce this format. The **mh_sync** field is used by MOSRA upon boot to search memory and locate all the memory modules. **mh_sysrev** is ignored by MOSRA. **mh_size** is the total size of the module including this header. **mh_owner** is also ignored. The **mh_name** field is the offset into the module of the name that is entered into the module directory list, and hence used to look up modules using the module system call API described above. **mh_exec** is the offset into the module of the start execution point. The **mh_mem** field gives the total amount of memory required for static data by the program. This includes the initialised static data, whose initial values are stored in the module at offset **mh_idata**, and the uninitialised static data. The maximum stack size required is given by **mh_stack**.

When a new process is created an area of memory is allocated for the stack, the processes registers, and for the static data (**mh_mem** bytes). Next the initialised data is copied to the data area (work area) by the **init_work()** function in **../ys-kit/mosra/kernel/process.c**. Each process descriptor has a pointer to an area for saving the processes registers when not active, this is also kept in the work area. The stack pointer in this register set is initialised to point to the stack area and the address register A6 is initialised to point to the work area. The OS/9 convention for access to the data area is through A6 indirect addressing.

```
/*
 * header structure of data module
 */
typedef struct mod_data{
          SHORT mh_sync,        /* sync code (4afc) */
                 mh_sysrev;     /* system revision */
          LONG   mh_size,       /* module size */
                 mh_owner,      /* owner id */
                 mh_name;       /* module name */
          SHORT mh_undef[15],   /* unused in mosra */
                 mh_parity;     /* header parity code */
          LONG   mh_data,       /* offset to data */
                 mh_dsize;      /* data size */
} MOD_DATA;
```

The format for data modules is very similar, but no interpretation on the data is made.

2.2.3.4 Process

Types

This is a MOSRA internal structure. It need not be manipulated by user application code, and does not appear in the API specification.

```
/*
 * process descriptor structure
 */
typedef struct _pdsc{
          struct _reg         *pd_regp;      /* saved register address */
          SHORT               pd_id,         /* process ID */
                              pd_wid,        /* message waiting ID */
                              pd_stat,       /* process status */
                              pd_prio,       /* process priority */
                              pd_reglv;      /* saved irq mask level */
          struct mod_exec     *pd_modh;      /* pointer to module header */
          char                *pd_work;      /* work area address */
          struct _pdsc        *pd_next;      /* active process link */
          struct _messt       *pd_mesp;      /* recieved message link */
          char                *pd_stack;     /* stack area address */
          SHORT               pd_child;      /*  T_CHILD if tfork()'d */
          SHORT               pd_sem;        /* semaphore we're waiting on */
} PDSC;

#define PDSIZE 28
```

This is the structure used to represent a process. All exiting processes in MOSRA have an associated process descriptor. Processes in MOSRA can be in any of four states: **`S_RUN`**, **`S_WAIT`**, **`S_MESW`**, or **`S_SEMW`**[14]. All processes that are ready to run are in the **`S_RUN`** state and are kept in a linked list (**`D_APROC`**) in the system global table with the currently executing process always at the top of the list. Processes in the **`S_MESW`** state are blocked waiting for a message to arrive, and processes in the **`S_WAIT`** state are blocked as a result of calling **`sleep()`**. Once a process has called **`sleep()`** it will not be placed back in the **`S_RUN`** state until another process wakes it with a call to **`wakeup()`**. A process in the **`S_SEMW`** state is blocked while waiting for a semaphore to become free (it called **`semtake()`** in blocking mode).

The **`pd_regp`** field is used to store a copy of the processors registers when the process is not executing. **`pd_id`** is the process identifier (PID). The **`pd_wid`** is the source PID the process is **`S_MESW`**aiting on. If this is 0 a message from any process will wake it. One of the three process states is stored in **`pd_stat`**, and the process priority is stored in **`pd_prio`**. The messages received but not read by the process are linked into a list **`pd_mesp`**. When the process is on the active process list, the **`pd_next`** field is used for linking. The **`pd_modh`** and **`pd_work`** field point to the executable memory module and work area respectively. Finally the **`pd_reglv`** is used to store the IRQ mask level of this process. See the Interrupt & Exception Handling API above. In versions of MOSRA that support threads and semaphores, the **`pd_stack`** field stores the stack area address (allocated independently of the work area in these versions), the **`pd_child`** flags for a thread (hence it's doesn't free the static area during

---

[14] Versions of MOSRA that do not support semaphores do not use the **`S_SEMW`** state.

death()), and the **pd_sem** gives the semaphore ID if the thread is blocked waiting for a semaphore.

The source code for the MOSRA process API is located in the **../ys-kit/mosra/kernel/process.c** file.

2.2.3.5 Messages

Types

```
/*
 * data structure for message
 */
typedef struct _messt{
          struct _messt *ms_next;        /* pointer to the next message */
          int            ms_leng;        /* message lengs */
          SHORT          ms_scid;        /* message source ID */
          char           ms_body[2];     /* message bady */
} MESST;

#define MSSIZE 12

/*
 * data structure for wake up message( message without message body )
 */

typedef struct __messt{
          struct __messt *ms_next;     /* pointer to the next message */
          int            ms_leng;        /* message lengs */
          SHORT          ms_scid;        /* message source ID */
} _MESST;
```

These structures are used as the header to a MOSRA type message. The data following this header is not interpreted by MOSRA and may contain pointers, as messages are exchanged between processes simply by pointer passing. The **ms_scid** is the process PID of the sender, the **ms_next** field is used for linking the message into a list and the **ms_leng** field is the total length of the message in bytes - header and any user data. The source code for the message API is located in the **../ys-kit/mosra/kernel/message.c** file. The **recv_mess()** call will return a message from the queue **pd_mesp** in the callers process descriptor, that matches the source PID (0 matches any message). If there are no matching messages, the process is placed in the **S_MESW** state. The **send_mess()** call either places the message on the destination processes message queue, or if the destination process was in a **S_MESW** state and the message matches it's **pd_wid**, then the process is placed directly in the **S_RUN** state and the message pointer placed in the D0 register. This simulates a return from a system call (since the process is in **S_MESW** it must have blocked on a call to **recv_mess()** which never returned due to no messages being available).

2.2.3.6 Interrupts & Exceptions

Types

```
/*
 * interrupt table structure
 */
typedef struct _irqtbl{
          char           *iq_poll;        /* polling device address */
          char           iq_mask;         /* mask byte */
          char           iq_flip;         /* flip byte */
          LONG           (*iq_serv)(),    /* interrupt service address */
                         iq_static;       /* static storage address */
          SHORT          iq_prio;         /* interrupt priority */
          struct _irqtbl *iq_next;        /* pointer for nextt irq table */
} IRQTBL;

#define IQSIZE 22

/*
 * data structure for stacked registor at exception
 */
typedef struct _reg{
          LONG      d[8],      /* data register d0 to d7 */
                    a[7];      /* address register a0 to a6 */
          SHORT     sr;        /* status register */
          LONG      pc;        /* program counter */
} REG;
```

The MOSRA interrupt mechanism is explained in the API section above. The source code is located in the file **`../ys-kit/mosra/kernel/exception.c`**.

2.2.3.7 System Calls & Register Usage

The mechanism for MOSRA system calls from user programs utilises the **`TRAP`** instruction to activate a software interrupt. Specifically a **`TRAP #0`**. Each MOSRA system call has a *system call code* that is defined in the header file:

`../ys-kit/mosra/defs/mosra/syscall_No.h`

This *call code* is placed in the instruction word following the **`TRAP #0`** instruction in the user code. The MOSRA kernel **`TRAP`** handler then obtains the PC location of the **`TRAP`** instruction and hence the *call code* from the stack. The appropriate kernel function is then dispatched. The user program actually calls a system call stub function that performs this process. These system call stub functions are in a user link library whose source is located in the **`../ys-kit/mosra/lib/syscall`** directory. For example the implementation of the **`mfree()`** stub looks as follows.

```
/*
 * mfree( adrs )
 * SHORT *adrs;
 */

#include   <mosra/syscall_No.h>

#asm
mfree:
     trap      #0
     dc.w      F$MFREE
     rts
#endasm
```

The **`../yskit/mosra/kernel/mosra68000.a`** file contains the **`_syscall TRAP #0`** handler that obtains the call code and calls the C function **`syscall(fnum, arg1, arg2)`** in the file:

`../ks-kit/mosra/kernel/exception.c`

which dispatches the call. Upon return the **`_syscall`** assembly function executes the top process on the process list - the process that was interrupted, and then does an **`rte`** instruction (return from interrupt).

OS/9 Register Conventions

The convention for OS/9 function calling if for parameters to be placed in registers and on the stack, and the return code is returned in register **`d0`**. Before the call the first argument is placed into register **`d0`** and the second argument in register **`d1`**. Any further arguments are placed onto the stack in standard C convention.

The **`a6`** register is used for the static storage address pointer[15]. There may be other registers used by convention by OS/9 but no documentation was available when this was written.

[15] For reasons I do not understand the value in **`a6`** is always set to the static data address + $8000. See the **`set_a6`** routine in **`mosra68000.a`** and also the line **`p->pd_regp->a[6] = (LONG)p->pd_work + 0x8000`** from **`pcreate()`** in **`process.c`**.

2.2.4 The MOSRA directory

The MOSRA directory **`../ys-kit/mosra`** has the following structure.

```
      |-config
      |
      |-defs----|-mosra
      |
      |         |-backup
      |-kernel--|-objs
      |         |-rels
      |
      |         |-cstart
      |-lib-----|-rels
      |         |-syscall
      |
      |                              |-common
      |         |-Xterminal-|-bt-----|-get
      |         |                    |-put
      |         |                    |-work
      |         |
mosra-|         |-lib-------|-rels
      |         |-os9
      |         |
      |         |           |-backup
      |         |           |
      |-romance-|           |        |-common
      |         |-target----|        |-doc
      |         |           |-unixft-|-get
      |         |                    |-put
      |         |                    |-work
      |         |
      |         |                    |-common
      |         |-unix------|-bt-----|-get
      |                              |-put
      |                              |-work
      |
      |-startup
```

2.3 Function Modules

2.3.1 Ultrasonic sensor module

There are two implementations of the ultrasonic sensor hardware. The original Sonic hardware and the new HiSonic hardware [Ohno95]. The interface is identical for both, however if using the HiSonic hardware on a robot the user must define **HISONIC** before including the **ymbc_usr.h** file.

```
#define HISONIC
#include <ymbc_usr.h>
```

Both hardware versions have four US sensors, facing left, right, toward the front and toward the back of the robot. The interface is very simple. There is a function to get the range distance from a particular directional sensor, and a function to enable/disable some or all of the sensors.

2.3.1.1 API

---

int us_dist(int dir)

Description:

This function gets the range of a detected object from the specified sensor. The units are cm.

Parameters:

dir	The direction, one of **US_FRONT**, **US_BACK**, **US_LEFT** or **US_RIGHT**. If using the new 16 sensor ring[16], you may also pass an integer [0..15] for the sensor number to read.

Return:

The distance in cm or if no echo was detected by the sensor, the value **US_NOECHO**.

[16] This is the 16 sensor ring developed at Wollongong not the 12 sensor ring developed at Tsukuba.

`us_mask(int mask_pattern)`

Description:

The function allows the selective enabling or disabling of any of the sensors.

Parameters:

`mask_pattern` One of **`US_NOMASK`**, **`US_MASKALL`** or any logical AND of **`US_FMASK`**, **`US_BMASK`**, **`US_LMASK`**, or **`US_RMASK`** to disable selected sensors.[17] Only use **`US_NOMASK`** or **`US_MASKALL`** for the 16 sensor ring.

Return:

Void.

Examples

```
#define HISONIC
#include <ymbc_usr.h>

main()
{
      // Turn off all sensors
      us_mask(US_MASKALL);

      ...

      // Turn off just left and right sensors
      us_mask(US_RMASK & US_LMASK);

      ...

      // Turn on all sensors again
      us_mask(US_NOMASK);
}
```

2.3.1.2 Implementation

The implementation of the HiSonic function module software is not discussed in this document.

[17]Some implementations contain a bug that causes the left and right sensors to be confused. This only affects **`us_mask()`**. So **`us_mask(US_LMASK)`** may physically disable the right sensor, but the software will still return **`US_NOECHO`** for the distance on the left sensor - hence both left and right will be unusable.

2.3.1.3 Directory

```
         |-defs
         |-hard
         |-lib
         |
HiSonic- |-master-|-rels
         |-mmacro
         |
         |-module-|-rels
         |-rom

         |-SON----|-rels
         |-defs
         |-lib
         |
SONic--- |-master-|-rels
         |-mmacro
         |
         |-module-|-rels
         |-rom
```

2.3.2 ISeye Software United Environment (ISSUE)

The ISSUE module includes the *Adjustment and Interactive Drawing Tool* (AID), *Path Search Sensor* (PaSS) and *IASensor yoked* (AIS) systems in an integrated environment. The ISSUE API is currently undocumented[18].

2.3.2.1 Directory

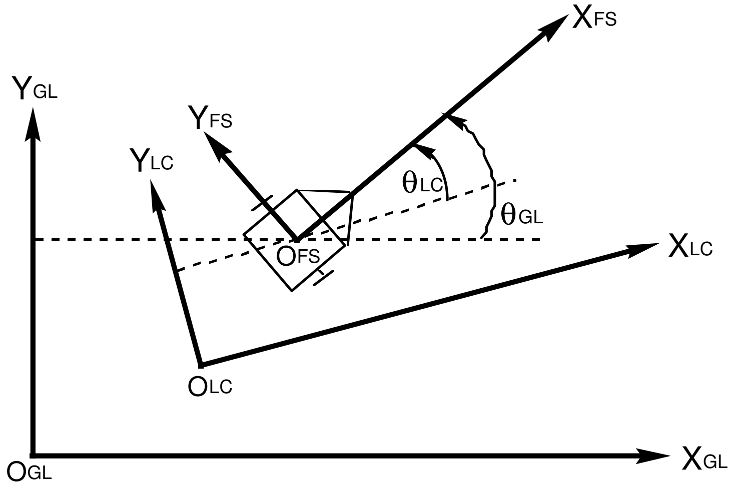
```
       |-defs
       |
       |-lib----|-rels
       |
       |-master-|-rels
       |
       |         |-AID------|-rels
       |         |
       |         |          |-objs
       |         |-IAS------|-params
ISSUE- |-module- |          |-rels
       |         |
       |         |-IScommon-|-rels
       |         |
       |         |-PaSS-----|-objs
       |         |          |-rels
       |         |
       |         |-eye_bank-|-rels
       |-rom
       |-sample
```

[18]ISSUE is not used in the Wollongong laboratory.

2.3.3 Spur (Locomotion module)

The vehicle command subsystem, or locomotion module is responsible for accepting hight level motion commands from the master module and controlling the wheel motors appropriately. It also uses the wheel shaft encoders to count wheel rotations and maintain odometry information. The software is named *Spur*. For a detailed description of Spur see "*Vehicle Command System and Trajectory Control for Autonomous Mobile Robots*" [Iida91][19].

Spur maintains three independent coordinate systems in (x,y,q). Global coordinates (GL) which are initially (0,0,0) when the robot is powered-on. These coordinates are typically used for mapping. The Local coordinates (LC) are an independent coordinate set that can be set relative to the GL coordinates, for example for negotiating an obstacle before returning to the previous tracked path. Lastly, the Front Side (FS) coordinate system is always relative to the robot. The (0,0,0) position is at the centre of the robot looking forward. See the diagram below.



The relationship between Spur coordinate systems.

The Spur commands can be divided into the following categories:

- Line and Arc Tracking
- Coordinate system setting
- Locomotion error adjustment
- Velocity and Acceleration control
- Other - Stopping, Spinning, Retrieving coordinates

Unless otherwise indicated all distance units are in millimetres (mm), and angles are measured in degrees. Note that many Spur commands have an alternate version suffixed with **_cm**. These use distance units of centimetres (cm) instead of millimetres. Velocity is always measured in $cm.s^{-1}$.

---

[19]This paper can be located in the English version of the Yamabico Hardware documentation folder [Yam95].

2.3.3.1 API

`Spur_line_GL(int x,int y,int th)`

`Spur_line_LC(int x,int y,int th)`

`Spur_line_FS(int x,int y,int th)`

`Spur_line_GL_cm(int x,int y,int th)`

`Spur_line_LC_cm(int x,int y,int th)`

`Spur_line_FS_cm(int x,int y,int th)`

Description:

These commands instruct Spur to track along the line passing through the point (x,y) in the direction th in the designated coordinate system until further notice. See [Iida91] for a diagram.

Parameters:

`x,y`	Cartesian Coordinate position that tracking line passes through.
`th`	Angle tracking lines makes with the coordinate system 0^{o} line.

Return:

Void.

Example

In this example the robot will track along a line at 45^{o} to the Global X coordinate axis. If it is at it's starting location it will track along a line 45^{o} to the right of the robot looking forward. Note that the robot will not rotate to 45^{o} then track forward, but rather will start moving forward immediately at 0^{o}, then veer right until it reaches the specified line.

```
#include <ymbc_usr.h>

main()
{
      Spur_line_GL(0,0,45);
}
```

Spur_arc_c_GL(int x,int y,int r)

Spur_arc_c_LC(int x,int y,int r)

Spur_arc_c_FS(int x,int y,int r)

Spur_arc_c_GL_cm(int x,int y,int r)

Spur_arc_c_LC_cm(int x,int y,int r)

Spur_arc_c_FS_cm(int x,int y,int r)

Description:

These commands instruct Spur to track along an arc with centre (x,y) and radius |r|. The rotational direction is counter-clockwise for positive r and clockwise for negative r. See [Iida91] for a diagram.

Parameters:

x,y	Cartesian Coordinate position that tracking arc is centred on.
r	Radius of tracking arc. Sign determines direction of rotation.

Return:

Void.

Spur_arc_t_GL(int x,int y,int th, int r)

Spur_arc_t_LC(int x,int y,int th, int r)

Spur_arc_t_FS(int x,int y,int th, int r)

Spur_arc_t_GL_cm(int x,int y,int th, int r)

Spur_arc_t_LC_cm(int x,int y,int th, int r)

Spur_arc_t_FS_cm(int x,int y,int th, int r)

Description:

These commands instruct Spur to track along an arc which touches the tangent through the point (x,y) with direction th and arc radius r. The rotational direction is counter-clockwise for positive r and clockwise for negative r. See [Iida91] for a diagram.

Parameters:

x,y	Cartesian Coordinate position that tracking arc tangent is centred on.
th	Angle of tangent line.
r	Radius of tracking arc. Sign determines direction of rotation.

Return:

Void.

`Spur_stop_GL(int x,int y,int th)`

`Spur_stop_LC(int x,int y,int th)`

`Spur_stop_FS(int x,int y,int th)`

`Spur_stop_GL_cm(int x,int y,int th)`

`Spur_stop_LC_cm(int x,int y,int th)`

`Spur_stop_FS_cm(int x,int y,int th)`

Description:

These commands instruct Spur to stop the robot when it gets close to the position (x,y) and angle th. Because of non-holonomic constraints the actual stoping position may no be exactly (x,y,th).

Parameters:

`x,y,th` Stopping position and angle.

Return:

Void.

`Spur_stop_q()`

`Spur_stop_Q()`

Description:

These two identical commands stop the robot with maximum acceleration. The preferred command to use is **`Spur_stop_q()`**.

Parameters:

None.

Return:

Void.

Spur_spin_GL(int th)

Spur_spin_LC(int th)

Spur_spin_FS(int th)

Description:

These commands instruct Spur to spin the robot on the spot to the angle th. This command will cause the robot to stop after the turn is completed.

Parameters:

th	Angle to turn to.

Return:

Void.

Spur_adjust_pos_GL(int x,int y,int th)

Spur_adjust_pos_LC(int x,int y,int th)

Spur_adjust_pos_FS(int x,int y,int th)

Spur_adjust_pos_GL_cm(int x,int y,int th)

Spur_adjust_pos_LC_cm(int x,int y,int th)

Spur_adjust_pos_FS_cm(int x,int y,int th)

Description:

These commands adjust the current coordinates of the robot in the specified coordinate system to the values supplied. This does not change the absolute values of coordinates used in the current tracking command being executed. Hence the effect is to modify the robot's notion of where it is in the coordinate space. This is typically used to correct accumulated odometry errors when other sources of position information are available, for example sensed landmarks.

Parameters:

x,y,th	The new values of the coordinates in the specified coordinate system.

Return:

Void.

Example

In this example the robot is tracking along a straight line directly forward. Then the coordinate system is adjusted so as to translate it to the robot's left. The effect of this will be that the robot veers right to track back onto the specified line through (0,0) at 0^o which is now to it's right in the coordinate space.

```
#include <ymbc_usr.h>

main()
{
	Spur_line_LC(0,0,0); // Track straight forward

	set_timer(5*SEC);    // let the robot go forward for 5 seconds
	timer_wait();

	Spur_adjust_pos_LC(0, 300, 0);    //  This  actually  translates  the
coordinate
	                                  //  system left 30cm and back by the
	                                  //   amount  the  robot  has  already
traveled
	                                  //  in  the  X  direction,  but  as  the
line
	                                  //   command  specifies  an  infinite
line, it
	                                  //  makes no difference to x.

}
```

`Spur_set_LC_on_GL(int x,int y,int th)`

`Spur_set_LC_on_LC(int x,int y,int th)`

`Spur_set_GL_on_GL(int x,int y,int th)`

`Spur_set_LC_on_GL_cm(int x,int y,int th)`

`Spur_set_LC_on_LC_cm(int x,int y,int th)`

Description:

These commands change the current coordinates of the first specified coordinate system to the values supplied relative to the second specified coordinate system. This is not a motion command but just changes Spur's coordinate values. It also changes the absolute coordinate values used in the current tracking state. Hence the motion of the robot will not be effected.

Parameters:

`x,y,th`	Values of the new coordinates relative to the second specified coordinate system.

Return:

Void.

`Spur_set_pos_GL(int x,int y,int th)`

`Spur_set_pos_LC(int x,int y,int th)`

`Spur_set_pos_GL_cm(int x,int y,int th)`

`Spur_set_pos_LC_cm(int x,int y,int th)`

Description:

These commands change the coordinates of the specified coordinate system to the values supplied. This is not a motion command but just changes Spur's coordinate values. It also changes the absolute coordinate values used in the current tracking state. Hence the motion of the robot will not be effected.

Parameters:

`x,y,th`	Values of the specified coordinate system relative to it's current values.

Return:

Void.

`Spur_set_vel(int vel)`

`Spur_set_vel_cm(int vel)`

Description:

This command instructs Spur to change the current maximum velocity (reference velocity) of the robot. If tracking the robot will accelerate until the desired velocity is reached.

Parameters:

`vel`	The new reference velocity.

Return:

Void.

`Spur_set_ang_vel(int angv)`

Description:

This command instructs Spur to change the current maximum angular velocity of the robot.

Parameters:

`angv`	The new reference angular velocity.

Return:

Void.

`Spur_set_accel(int acc)`

`Spur_set_accel_cm(int acc)`

Description:

This command instructs Spur to change the current maximum acceleration of the robot.

Parameters:

`acc`	The new maximum acceleration.

Return:

Void.

`Spur_set_ang_accel(int alpha)`

Description:

This command instructs Spur to change the current maximum angular acceleration of the robot.

Parameters:

`alpha`	The new maximum angular acceleration.

Return:

Void.

`Spur_servo()`

Description:

This command instructs Spur to engage the motor servoing if it is not already engaged. The robot will not be free-wheeling once it has been engaged. Any attempt to move the robot manually will cause the robot to attempt to accelerate and move back to it's current global coordinates.

Parameters:

None.

Return:

Void.

`Spur_servo_free()`

Description:

This command instructs Spur to free the motor servoing. The robot will then be free-wheeling and may be manually pushed. Note that Spur still keeps odometry information up-to-date. Hence the robot will still know it's current global position after being manually pushed.

Parameters:

None.

Return:

Void.

`Spur_get_pos_GL(int *x0,int *y0,int *th0)`

`Spur_get_pos_LC(int *x0,int *y0,int *th0)`

`Spur_get_pos_GL_cm(int *x0,int *y0,int *th0)`

`Spur_get_pos_LC_cm(int *x0,int *y0,int *th0)`

Description:

These commands obtain the current coordinate values in the specified coordinate system.

Parameters:

x0,y0,th0 The current coordinates in the specified coordinate system. Note that the address of variables of **int** type must be supplied to receive the values.

Return:

Void.

Spur_get_vel(int *vel,int *angv)

Spur_get_vel_cm(int *vel,int *angv)

Description:

These commands obtain the current linear and angular velocities. Note that the address of variables of **int** type must be supplied to receive the values. These are the reference maximum velocities not the actual current velocity of the robot. Use **Spur_near_vel()** or **Spur_near_ang_vel()** to test the current robot velocities.

Parameters:

vel The current linear velocity.

angv The current angular velocity.

Return:

Void.

---

int Spur_near_pos_GL(int xx, int yy, int r)

int Spur_near_pos_LC(int xx, int yy, int r)

int Spur_near_pos_GL_cm(int xx, int yy, int r)

int Spur_near_pos_LC_cm(int xx, int yy, int r)

Description:

This call determines if the robot is near the specified position (x,y) within a tolerance radius r.

Parameters:

xx,yy Cartesian coordinate position the robot may be near.

r The tolerance radius.

Return:

TRUE if near the specified coordinates within the tolerance, **FALSE** if not.

`int Spur_near_ang_GL(int ang,int error)`

`int Spur_near_ang_LC(int ang,int error)`

Description:

This call determines if the robot's angle is near the specified angle **`ang`** within an error angle **`error`**.

Parameters:

`ang`	Angle the robot may be near.
`error`	The error tolerance angle.

Return:

`TRUE` if near the specified angle within the tolerance, **`FALSE`** if not.

`int Spur_near_vel(int vel,int error)`

`int Spur_near_vel_cm(int vel,int error)`

Description:

This call determines if the robot's current velocity is near the specified velocity **`vel`** within an error tolerance **`error`**.

Parameters:

`vel`	The velocity the robot may be near.
`error`	The error tolerance velocity.

Return:

`TRUE` if near the specified velocity within the tolerance, **`FALSE`** if not.

int Spur_near_ang_vel(int angv,int error)

Description:

This call determines if the robot's current angular velocity is near the specified angular velocity **angv** within an error tolerance **error**.

Parameters:

angv The angular velocity the robot may be near.

error The error tolerance angular velocity.

Return:

TRUE if near the specified angular velocity within the tolerance, **FALSE** if not.

Spur_over_line_GL(int xx,int yy,int th)

Spur_over_line_LC(int xx,int yy,int th)

Spur_over_line_GL_cm(int xx,int yy,int th)

Spur_over_line_LC_cm(int xx,int yy,int th)

Description:

This call determines if the robot is over the line through (xx,yy) at angle th.

Parameters:

xx,yy Point which line passes through.

th Angle of the line.

Return:

TRUE if the current position is over the specified line[20], **FALSE** otherwise.

2.3.3.2 Implementation

The Spur locomotion system is currently implemented as an independent function module on a Yamabico CPU bus card. The source for this implementation can be located in the directory **../ys-kit/module/Spur-16/module**. The implementation at the algorithmic level is not discussed in this document, but is discussed in [Iida91A, Iida91]. What follows is a brief overview of the function of the source code. A description of the locomotion software in the

[20]Need to clarify exactly what 'over the line' means.

context of communication with the master module is also given in the *case study* of *Section 2.4 Inter-module Communication and the Yamabico Bus*.

The Spur software is interrupt driven. The **startup** module (**../module/startup.c**) that is loaded onto the locomotion board starts romance as usual, then **mfork()**'s the **spur** module. The Spur main function from **spur.c**, calls **_spur_init()** then busy-wait's in an infinite loop. The **_spur_init()** function carries out the following steps in sequence .

<u>Initialises the hardware pointers - **_hwinit()**</u>

The Spur software access three types of Yamabico hardware. The communication of locomotion commands from the master module and state information to the master module is via *Dual Port Memory* (DPM). A description of this mechanism and the DPM is in section 2.4. The *Programmable Timer Module* (PTM) is used to deliver periodic interrupts to the CPU and activate the interrupt routine which ultimately does the work of the locomotion software. The 4 Channel *Pulse Width Modulator* Signal Generator (PWM) is used to control the motor currents independently.

This function initialises the pointer variables **ptm**, **dpm**, **pwm**, **mode**, and **cnt** to point to the respective hardware addresses. The **cnt** and **mode** variables are for wheel shaft encoder feedback.

<u>Initialises the software state variables - **_swinit()**</u>

This function initialises the variables that represent the dynamic state of Spur. This includes resetting the coordinate system, setting the initial acceleration and velocity to 0, calculating initial gains for the motors from the velocity and setting the *current mode* to stop.

The current mode of Spur is represented by the **cmode** variable. This is a C structure/union with substructures that look as follows (from **../Spur-16/defs/mode_ctl.h**)

```
/* for mode control structure */
struct mode_ctl_str {
    char mode;        /* Control mode */
    union mode_para para;
};

union mode_para {
    struct line_para_str line_para;
    struct accel_para_str accel_para;
    struct stop_para_str stop_para;
    struct circle_para_str circle_para;
};

/* for line trace mode parameters */
struct line_para_str {
    int x_org;
    int y_org;
    int th_org;
};

/* for acceleration mode */
struct accel_para_str {
    int vel;
};
```

```
/* for stop mode parameters */
struct stop_para_str {
    int x_stop;
    int y_stop;
    int th_stop;
    int sumx;
    int sumth;
};

struct circle_para_str {
    int x_cent;
    int y_cent;
    int radi;
};
```

The major modes are **`STOP`**, **`LINE`**, **`CIRCLE`**, **`FREE`**, and **`ACCEL`**. The modes and their associated parameters are self explanatory.

Sets up the table data - **`_tblinit()`**

This function initialises a table **`tbl[]`** for 2D current control. The data for the table is different for each robot body and is included from a file in the **`../table/tdata`** directory.

Registers an interrupt routine for the PTM - **`_reg_ptm()`**

This function registers an interrupt routine for the PTM. The routine is **`timirq()`** from **`../module/timirq.c`**. This will be called every 5ms.

Registers an interrupt routine for the DPM - **`_reg_pdm()`**

This function registers an interrupt routine for the DPM. The routine is **`dpmirq()`** from **`../module/dpmirq()`**. This will be called when the master module writes a Spur command into the SIMP. See section 2.4 for details.

Initialises the PWM hardware - **`_initpwm()`**

This function simply initialises the PWM hardware.

Initialises the DPM hardware - **`_initpdm()`**

This function clears the DPM SIMP and command areas.

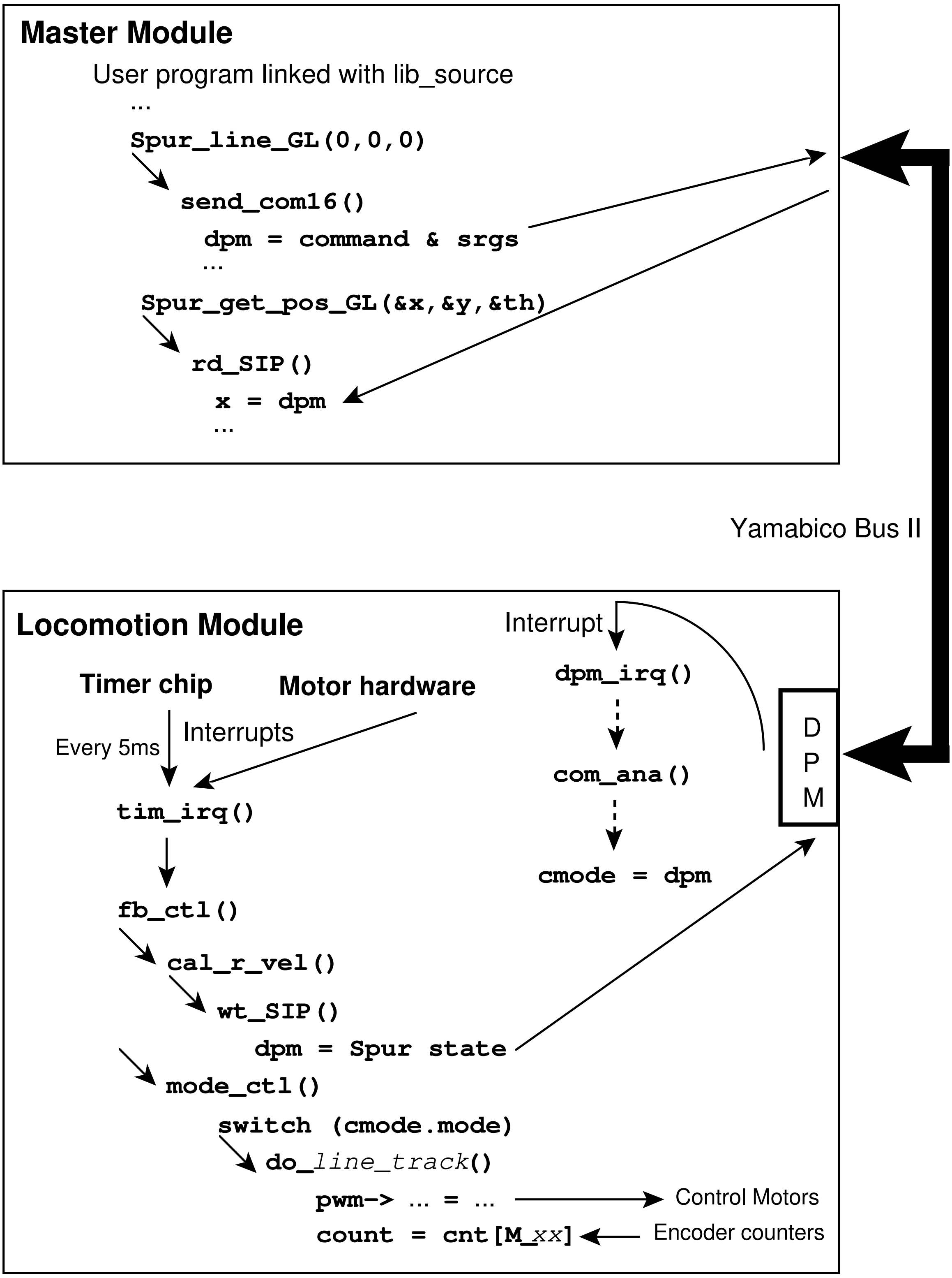
Initialises the PTM hardware - **`_initptm()`**

This function initialises the PTM to interrupt the CPU at 5 millisecond (ms) intervals.

Once initialisation is complete the main program busy waits in an infinite loop. The work is then carried out by the **`timirq()`** and **`dpmirq()`** routines. The **`dpmirq()`** routine is activated when the master module writes a new command into the DPM. This invokes the appropriate command function which just modifies the current state of Spur (**`cmode`**) to reflect the requested command action. This is explained in section 2.4.

The **`timirq()`** function calls **`read_cnt()`** to read the current wheel encoder counter values, then calls the feedback control routine **`fb_ctl()`** (**`timirq.c`**). The **`fb_ctl()`**

function calls on other functions to calculate various values, such as the robot velocity (**cal_r_vel()**), depending on the current mode. It implements the feedback control as described in the paper [Iida91A]. The **cal_r_vel()** function also updates the DPM SIMP information making it available to the master module. Hence the SIMP is updated every 5ms. To summarise, the architecture looks as follows.



Spur locomotion software and Master module architecture

2.3.3.3 Directory

```
      |-DPM
      |-defs
      |-doc
      |-exp
      |-lib
      |
      |-lib_source--|-rels
      |
      |-line_tr_sim-|-data
      |             |-setup
      |
      |-master------|-obj
      |             |-rels
      |
      |-module------|-obj
      |             |-rels
Spur- |-obavo
      |-rom
      |-rr1
      |-rr2
      |-rr_avo
      |-sample
      |-simlib
      |-simulator
      |
      |             |-mktable
      |-table-------|-setup
      |             |-tdata
      |             |-tempdir
      |-tosim
```

2.3.4 Voice generator module

The voice generation function module has the ability to say numbers in decimal and hexadecimal[21], string of romanji characters, and pre-recorded sample modules. All requests for speech are queued and the function returns to the caller immediately. See the document **ys-kit/module/Voice/doc/library_func.txt** for Japanese documentation.

A description of the available functions is given below[22].

2.3.4.1 API

---

voice_init()

Description:

This function initialises the voice function module and must be called prior to usage of any other voice module functions.

Parameters:

None.

Return:

Void.

---

voice_set(int amp, int rate)

Description:

Set the amplitude and rate of spoken voice.

Parameters:

amp	Amplitude.
rate	Rate.

Return:

Void.

---

[21]Only in Japanese

[22]The Voice module is not used at the Wollongong laboratory, hence the documentation is incomplete.

`v_boadCHK(int boad)`

Description:

Check the existence of the specified Board and if detected plays a recorded message indicating the board is OK. The check is done by checking the accessibility of the board's DPM. The recorded message data is read from a data memory module of sampled data with pre-defined names for each board. The pre-defined sample module names are: **`sonic_ok`**, **`eye_ok`**, **`spur_ok`** and **`voice_ok`**.

Parameters:

`boad`	The board to check[23]. This is actually the address of the board's DPM. These are defined in **`vusr.h`**.

Return:

Void.

Example

```
#include <ymbc_usr.h>
#include <vusr.h>

main()
{
      /* Check sonic, ISeye, and Spur boards.  Voice will announce OK message
if
            the board is OK */
      v_boadCHK(SON);
      v_boadCHK(ISe);
      v_boadCHK(SPR);
}
```

`sayd(int num)`

Description:

Say the specified decimal.

Parameters:

`num`	Number to say.

Return:

Void.

[23]Note boad is just a Japanese misspelling of Board.

`sayx(int num)`

Description:

Say the specified hexadecimal number.

Parameters:

`num`	The number to say.

Return:

Void.

`says(int num)`

Description:

Say the pre-defined sentence stored on the voice module with index number **`num`**. All the pre-defined sentences are currently in Japanese.

Parameters:

`num`	Index of pre-defined sentence to say.

Return:

Void.

`sayw(char *str)`

Description:

Say the romanji string specified[24].

Parameters:

`str`	The romanji string to say.

Return:

Void.

[24]Note that the current implementation is intended to speak Japanese, hence some characters are converted. Specifically ‘l’ -> ‘r’, ‘v’ -> ‘b’, ‘j’ -> ‘z’ and ‘c’ -> ‘s’.

speakf(char *fmt, int ag1, int ag2,...,int ag9)

Description:

Say a C printf style formatted string.

Parameters:

fmt The format string. This parameter is similar to, but more restricted than, C's **printf()** format function. The allowable format specifiers are:

- **%c** character
- **%d** integer (decimal)
- **%x** integer (hexadecimal)
- **%a** set amplitude to arg and rate to default
- **%r** set rate to arg and amplitude to default

agN N = [1..9], the arguments

Return:

Void.

---

sayp(char *str)

Description:

Play the pre-recorded sounds memory module with the specified name.

Parameters:

str The name of an existing MOSRA memory module containing the sample data.

Return:

Void.

`say_flush(int thre)`

Description:

This function is for flushing the queued say requests. If the number of queued requests is greater than *thre* then the oldest requests are aborted/dequeued leaving only the newest *thre* requests.

Parameters:

`thre`	The thresh-hold number of requests to leave queued.

Return:

Void.

`int say_ended(int rest)`

Description:

This function returns TRUE if the number of queued voice requests on the voice module is equal to **`rest`**, FALSE otherwise.

Parameters:

`rest`	Test number of remaining requests.

Return:

TRUE if remaining requests queued is **`rest`**, FALSE otherwise.

2.3.4.2 Implementation

The implementation of the voice module is not discussed in the document.

2.3.4.3 Directory

```
          |-defs
          |-doc
          |-hard
          |-lib
          |-lib_source
          |-master
          |
          |                                |-etc
          |                                |
          |                                |-j50--|-j50
          |             |-datae7--|-num
          |             |                  |-sent
          |             |                  |-wd
          |             |
          |             |                  |-etc
          |             |                  |-j50
Voice-|-mkv---------|-datae9--|-num
          |             |                  |-sent
          |             |                  |-wd
          |             |
          |             |                  |-etc
          |             |                  |
          |             |                  |-j50--|-j50
          |             |-dataea--|-num
          |                                |-sent
          |                                |-wd
          |
          |-module-----|-objs
          |                 |-rels
          |-pcmdata1
          |-pcmdata2
          |
          |-rom---------|-startup
          |-test
```

2.3.5 Timer functions

The timer functions are not implemented in a separate function module, but as an independent process that executes on the master module. The **`set_timer()`** and **`timer_wait()`** function interact with the **`TIMER`** process, hence blocking the process that calls **`timer_wait()`** until the time expires. The **`read_SRTKEI()`** and **`compSRTKEI()`** function simply read the global system timer.

2.3.5.1 API

`set_timer(int count)`

Description:

This function is used in conjunction with the **`timer_wait()`** function to delay execution for a specific amount of time. Other program code may execute between the **`set_timer()`**...**`timer_wait()`** pair provided it does not take longer than count $1/100^{Th}$ of a second to execute. Note that the definition **`SEC`**==100 is available.

Parameters:

`count` Number of $1/100^{Th}$ of a second to delay.

Return:

Void.

`timer_wait()`

Description:

This function is used in conjunction with the **`set_timer()`** function to delay execution for a specific amount of time. Once called the execution is delayed until the **`count`** time has expired from when **`set_timer()`** was called.

Parameters:

None.

Return:

Void.

`int readSRTKEI()`

Description:

This function returns the current value of the quasi-real time clock. The units are 10 msec.

Parameters:

None.

Return:

Current time in units 10 msec.

`int compSRTKEI(int t0,int time)`

Description:

This function compares the value of the specified times. If *time* represents a time greater that of equal to *t0* TRUE is returned.

Parameters:

`t0`	Initial time to compare. Units are 10 msec.
`time`	time to compare with **`t0`**.

Return:

`TRUE` if **`time`** > **`t0`**, **`FALSE`** otherwise.

2.3.5.2 Implementation

The **`set_timer()`** and **`timer_wait()`** functions can be found in the file **`../ys-kit/module/mmKEI/lib/timer6340.c`**[25]. The **`set_timer()`** function allocates and sends a **`struct timess`** message to the **`TIMER`** process (PID **`TIMEMON`**). The TIMER process is implemented in **`../ys-kit/module/mmKEI/iomon/timer.c`**. The main loop wait for incoming messages, and retains a list of timer requests. As each timer request expires a message is sent back to the sending process. The TIMER process uses interrupts from the timer device to efficiently wait for times to expire without busy waiting. When a process makes a call to **`wait_timer()`**, **`wait_timer()`** just blocks waiting for a message from the TIMER process.

---

[25] For other Master Module versions the directory will be other than **`mmKEI`**. For example the Wollongong version of the master module source is in the **`mmW`** directory.

The **`readSRTKEI()`** and **`compSRTKEI()`** functions are implemented in the file **`../ys-kit/module/mmKEI/lib/srt_KEI.c`**. They simply read and compare against the free running system timer.

2.3.6 Whisker functions

Some Yamabico robots have a number proportional passive whisker sensors[26]. These are accessed by the whisker library API. This whiskers are accessed by an integer index [0..7] or by the PCB socket numbers **`WJ_3`** … **`WJ_10`**. Some synonyms also exist (**`WLeftFront`**, **`WLeftBack`**, **`WFrontRight`** and **`WFrontLeft`**).

2.3.6.1 API

`ReInitWhiskers()`

Description:

This function initialises or re-initialises the whisker software. It must be called prior to calling any other whisker functions. The whisker module will not access the whisker hardware or execute until this function is called. Hence it is acceptable to have the whisker module in ROM and running on a robot that has no whiskers connected, as it will do nothing until this function is called.

Parameters: None.

Return: None.

---

[26] Currently only Flo at the Wollongong laboratory. The implementation currently connects the hardware to the master module, and hence the whisker module is an executable module on the master module ROM.

`CalibrateWhisker(int whisker)`

Description:

This function calibrates the centre position of the specified whisker to it's current physical position. This is called to set the current physical position (usually the rest position) to the 0 point. The readings will then be positive or negative depending on the direction of deflection.

Parameters:

`whisker`	The whisker number to calibrate.

Return: None.

`int ReadWhisker(int whisker)`

Description:

This is the main function used to read whisker values. The values returned have been adjusted to the calibrated centre (and hence are signed values), possibly reversed in sense and are averaged over a number of samples (set using **`SetNoSampAverage()`**).

Parameters:

`whisker`	The whisker number to read the current averaged value of.

Return:

The whisker sensor value.

`int ReadRawWhisker(int whisker)`

Description:

This function returns the raw value of a whisker sensor reading as obtained from the hardware A/D converter. It is not averaged or centre calibrated.

Parameters:

`whisker`	The whisker number to read the current raw value of.

Return:

The whisker sensor value.

`int SetSampleFreq(int FreqHz)`

Description:

The whisker module samples each whisker at a fixed sampling rate (all whiskers at the same rate). This call is used to change the default rate or to disable sampling. The default is 20Hz and the valid range is 1Hz…60Hz. A value of 0 will turn off sampling and the whisker module will no longer use the CPU until the frequency is reset (or **`ReInitWhiskers()`** is called).

Parameters:

`FreqHz`	The whisker sampling frequency in Hz or 0.

Return:

The old sampling frequency (current previous to the call).

`int SetNoSampAverage(int NoSamples)`

Description:

This function is sets the number of sample over which the read whisker values are averaged. The default is 5 and the valid range is [1..50]. If the value 0 is passed the whisker module will not do averaging at all. In this case the result of calling **`ReadWhisker()`** will be meaningless, but the raw un-averaged values may be read using **`ReadRawWhisker()`**.

Parameters:

`NoSamples`	The number of samples to average over, or 0 to disable calculation of average values.

Return: Undefined.

`SetDebug(int Channel)`

Description:

The whisker module can send debugging output to either the ROMANCE or RADNET consoles. This is useful to display a continuous readings of whisker values when calibrating hardware etc. If averaging has been disabled, only raw values will be displayed.

Parameters:

`Channel`	One of CON, NET or -1. To disable debugging pass -1 (the default), to enable display of whiskers every one second specify which console.

Return: None.

`SetSense(int whisker, int Sense)`

Description:

It is sometimes desirable to reverse the numeric range of the sensor readings, for example if the whisker connector was wired backwards.

Parameters:

`whisker`	The whisker number to set the sense of.
`Sense`	Either 1 or -1. If 1 the sense is as read from the hardware, if -1 the sense is reversed

Return: None.

`QuitWhiskers()`

Description:

Calling this function causes the whisker module to exit. (Calls **`death()`**, and hence can be unlinked or restarted with execute). Issuing whisker calls after this will cause the caller to block forever. Even if the whisker module is restarted, client programs **must** call **`ReInitWhiskers()`** again.

Parameters: None.

Return: None.

2.3.6.2 Implementation

The current implementation is just an executable module that runs on the master module. The library calls communicate with it via message passing, with the exception of **`ReadWhisker()`** and **`ReadRawWhisker()`**, which just read from an array of values shared between the whisker module and the clients. The address of this array is passed from the whisker module to a client when **`ReInitWhiskers()`** is called. The whisker module accesses a multiplexed Analogue to Digital (A/D) converter via the master module parallel port. The whiskers themselves are currently just variable rotary potentiometers. The sampling rate is achieved just by using the timer module functions, and hence two messages are exchanged every sampling period. For this reason the sampling period should not be set too high or the CPU will be loaded with message passing between the whisker module and the timer module[27]. This timing method may change in the future.

[27] There seems to be a bug in the timer module software where by occasionally it doesn't reply to a timer request (**`wait_timer()`** never returns). This seems only to show up when messages are sent at a high rate as with the whisker module.

2.3.7 ROMANCE & RADNET console functions

The ROMANCE and RADNET console functions are used to do Input/Output through one of the serial ports on each CPU board. The ROMANCE functions are used for the first port (which is usually connected using a cable to a UNIX host executing the **`romanceu`** program). The RADNET network functions use the second port and communicate with a UNIX host running the RADNET software. Ultimately the output goes to the **`radcon`** console utility. The RADNET Host software is documented in a later section.

2.3.7.1 ROMANCE API

`write_cons(char *form_str)`

`write_cons(char *form_str, int data)`

`write_cons(char *form_str, char *data)`

Description:

This function is for output to the **romance** console. The function is similar to, but more restricted than, C's **`printf()`** function. The allowable format specifiers are:

- **`%c`** character
- **`%s`** C string
- **`%d`** integer (decimal)
- **`%x`** integer (hexadecimal)
- **`%b`** integer (binary)

Parameters:

`form_str` A format string in the **`printf()`** style, but **`write_cons()`** only allows **`0`** or **`1`** format specifiers in the string.

Return:

Void.

`char *read_cons(char *form_str, char *data, int *count)`

Description:

This function is for input from the **`romance`** console. The function is similar to, but more restricted than, C's **`scanf()`** function. The allowable format specifiers are:

- **`%c`** character
- **`%s`** C string
- **`%d`** integer (decimal)

- **%x** integer (hexadecimal)
- **%b** integer (binary)

Parameters:

form_str A format string in the **scanf()** style. The format specifiers are limited to those listed above.

data The address of an appropriate type of variable at which the input will be stored.

count The address of an integer into which the number of bytes read from the console will be stored.

Return:

Unknown.

2.3.7.2 RADNET Console API

RADNET provides two functions that closely mimic the behaviour of the ROMANCE functions above. These functions, however, interact with the user via the **radcon** console utility which may run on any UNIX machine. The **radcon** utility connects to the RADNET link server, and hence the robot, via the Internet. For more details see the RADNET documentation later in this document.

---

write_port(int Channel, char *form_str)

write_port(int Channel, char *form_str, int data)

Description:

This function is for output to the **romance** or RADNET console. The parameters are similar to **write_cons()**.

Parameters:

Channel One of **CON** or **NET**. If **CON** the output will go to the romance console, if **NET** the output will go to the RADNET console.

form_str As for **write_cons()**.

Return:

Void.

`read_port(int Channel, char *form_str, char *data, int *count)`

Description:

This function is for input from the **`romance`** or RADNET console. The parameters are similar to **`read_cons()`**.

Parameters:

`Channel` One of **`CON`** or **`NET`**. If **`CON`** the input will come from the romance console, if **`NET`** the input will come from the RADNET console.

`form_str, data, count` As for **`read_cons()`**.

Return:

Void.

2.3.7.3 ROMANCE Implementation

The console functions use ROMANCE to do I/O through the serial port (using the ACIA device). ROMANCE is implemented as an independent MOSRA process. One function of ROMANCE is to provide a menu interface via the serial port to the host computer to allow program upload/download, memory module manipulation and other services. The other function is to provide the console I/O described here.

The ROMANCE source code is located in the **`../ys-kit/mosra/romance`** directory. Communication with the user program process is via the MOSRA message passing facility (see MOSRA API section). The console functions described above just send a MOSRA message to the ROMANCE process, which has a pre-defined process ID. The receipt of a message wakes the main loop in the ROMANCE process and it carries out the I/O via the serial port. The actual serial I/O is interrupt driven. The ROMANCE process installs an interrupt handler for the serial port when first started by the **`startup`** module.

The **`write_cons()`** and **`read_cons()`** function are available to user programs by linking with the **`romancelib.l`** library, hence are implemented in the **`../romance/lib`** directory (**`write_cons.c`** and **`read_cons.c`**). These functions simply call the read/write routines provided in the **`writefunc.c`** and **`readfunc.c`** source files. For example, **`_cwritech()`** creates a message of type **`MESST`** (standard MOSRA message header type) and sends it to ROMANCE.

```
_cwritech(dir,str,count)
char dir;
char *str;
int  count;
{
    MESST *m;
    int i,l,head;

...
    m=(MESST *)malloc(10+l);
    m->ms_scid=getpid();
    m->ms_leng=l;
    m->ms_body[0]=STX;
    m->ms_body[1]='W';
    for (i=0;i<count;i++) m->ms_body[head+i]=str[i];
    m->ms_body[l-1]=NULL;                    /* STX W  < data > NULL    */
    if (dir==STDOUT){ m->ms_body[2]=SI;      /* STX W SI <data> SO NULL */
                      m->ms_body[l-2]=SO;
                 }
    if (send_mess(ROMANCE,m)) return(1);  /* send to ROMANCE */
    else return(0);
}
```

The ROMANCE process source is located in the directory **`../romance/target`**. When ROMANCE receives this message in it's main loop in the **`wait()`** function (**`main.c`**), it calls the **`message()`** function to process the message. If, for example, the message indicated a write (**`body[1] == 'W'`**), then **`message()`** calls **`writestr()`** which actually outputs the string to the ACIA's serial port (using **`writech()`**).

2.3.7.4 Directory

```
                  |-lib------------|-rels
                  |-os9
                  |
                  |                |-backup
                  |                |
romance----       |                |            |-doc
                  |-target---------|            |-common
                  |                |-unixft---  |-get
                  |                             |-put
                  |                             |-work
                  |
                  |                |-common
                  |-unix-----------|-get
                                   |-put
                                   |-work
```

2.4 Networking

The Yamabico Radio Network RADNET[28] is a software system that enables two-way communication between any number of Yamabico's and host computers. It consists of software components for both the Robot and host machines on a network. The current implementation executes the robot software on the master module and communicates over point-to-point radio modem links connected via the master module serial port. The host side of the link is a UNIX workstation with the radio modem also connected via a serial port.

The Network API on the robot side provides user programs, currently under MOSRA, with services for sending and receiving unreliable datagrams. Datagrams are addressed using IP numbers, where the robots have special numbers starting at zero, and a port number. Using ports it is possible to have a large number of independent channels of communication with another robot or host machine. The API on the host machine is provided by a client link library. This provides a similar datagram API as available on the robot in addition to functions for directly accessing Spur locomotion functions remotely and up/downloading OS/9 modules over the link.

User utility programs are provided for convenient interaction and control of the robots (downloading programs and executing them, etc.). These programs rely on the client library for communication with the robots.

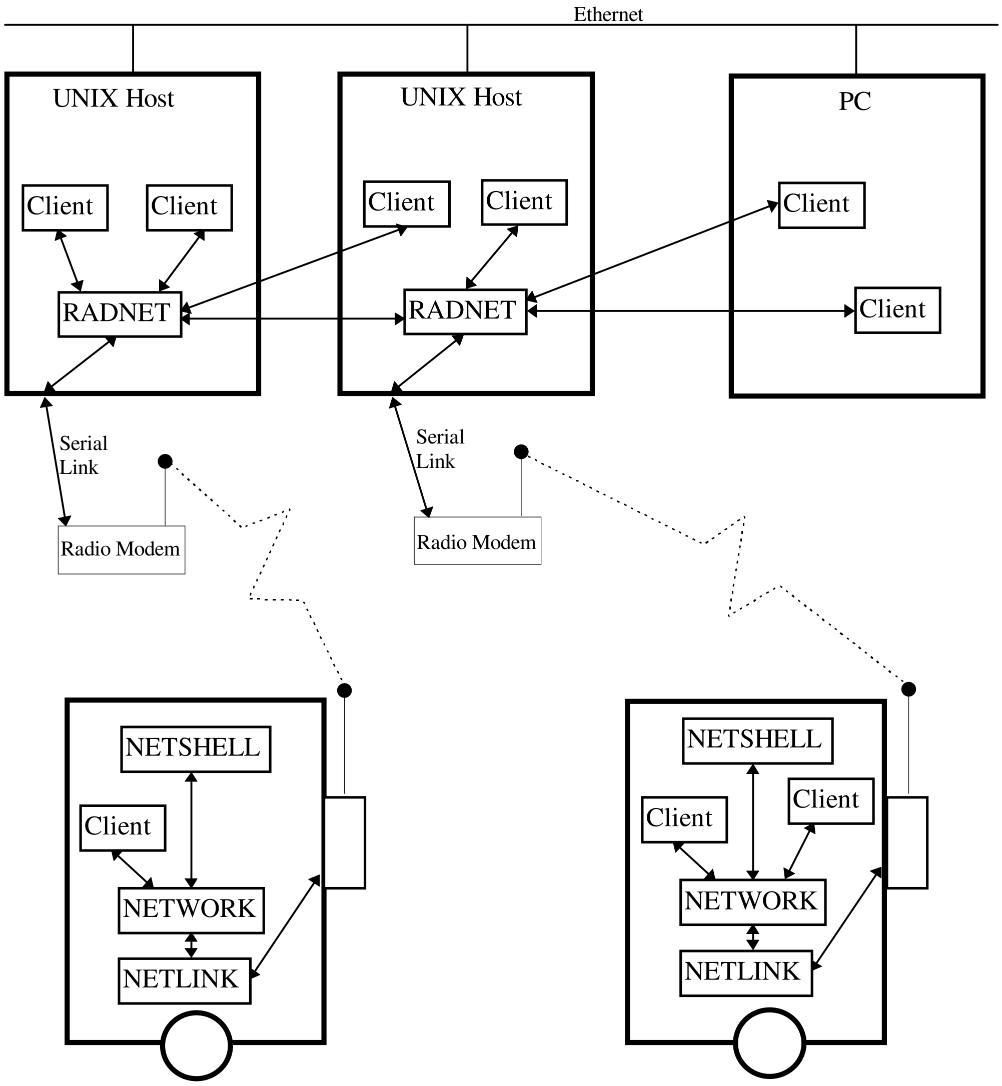
The following sections document the general RADNET architecture, the user programs, and the robot and host side client API's.

2.4.1 Architecture

The RADNET software supports multiple robots each with a point-to-point link between the robot and a UNIX host. The host need not be the same machine for each robot, although if the host supports multiple serial ports it is possible to connect multiple radio modems. The host end of each robot link runs a copy of the RADNET program in the background. This is called the *RADNET link server*. It manages the raw communication with it's robot over the modem link and also routes packets between *RADNET Clients*, other RADNET link servers and the robot.

As shown in the figure below there can be any number of RADNET clients running on the UNIX hosts or PC's. A client may connect to any RADNET link server and will be able to communicate with any robot or other client. The link servers manage routing of packets to the appropriate host for sending to a robot or a client. Note that the client's IP address is the IP address of the machine on which it is executing. All communication between RADNET link servers and clients uses BSD UNIX Sockets.

[28]Note that RADNET was developed at Wollongong University and is an independent and unrelated system to the CARNET networking system developed at Tsukuba University that employs broadcast technology with token passing.



RADNET Architecture

All the RADNET source code is located in the **…/ys-kit/module/mmW/network** directory. Subdirectories exist for the robot and UNIX sides of the code, and beneath them, subdirectories for library code, and the different OSI layers, etc.

2.4.2 Network User Utility Programs

This section describes the user utility programs available for interacting with the robots over the network. These programs are for conveniently uploading, downloading and executing robot programs from the UNIX host development environment. They also provide other facilities as described below. Each program uses the UNIX client library for communication with the robots, and hence when run each program must connect to a RADNET link server. Command line options allow the server host and robot to be selected.

2.4.2.1 Remote

The **remote** program is a menu driven program for interacting remotely with a robot over the network. The program can be run on any machine on the Internet, provided an appropriate RADNET server host is specified and the network latency is not too high[29]. Command line usage is as follows:

```
remote [-r <robot> -s <RADNET server host> -dk]
   -r  RobotNumber (default 0 = FLO)
   -s  LinkServer_Machine_Host_Name (default terumi)
   -dk Don't Spur_servo_free() or us_mask(MASK_ALL) at startup
```

Pressing 'h' for help after the program is running will display the help menu. Facilities are available for module manipulation, checking memory, module and process status, and for driving the robot using the numeric keypad.

If the message "**Remote: Can't connect to NetShell**" is display when the program is started it means that the **NetShell** module on the robot could not be contacted. This indicates either that the robot is turned off, rebooting, the master module CPU is so heavily loaded it can't reply, or a problem exists with the robot's networking software or the modem link. The RADNET link server, however, is operating correctly. Should the message "**OpenConnection(): Can't connect to server.**" Be displayed instead, this indicates that either the specified host has no RADNET link server, or that the server is not running. In this case it must be started - see the documentation for **RADNET** below.

If the program started correctly, and 'h' for help is pressed, the menu looks as follows:

```
** Remote v1.60 **

(Q)uit [ESC]                    (H)elp


COMMAND: Help

(D)ownload module from UNIX       (A)re you there?
Upload module to U(N)IX           (C)hange robots
(R)eset robot                     Sensors (O)ff
(U)nlink module                   (S)ensors On
(Z)ero local coords               (M)emory Status
(K)ill (ServoFree&SensorsOff)

(P)rocess list                    (L)ist modules
E(X)ecute module                  (!) UNIX command

Robot control:
             7  8  9              +
              \ ^ /               ^
  Direction  4< 5 >6   Velocity   0
              / v \               v
             1  2  3              -

(Q)uit [ESC]                      (H)elp

COMMAND:
```

---

[29] For example, executing **remote** on a machine located in Japan and connecting to a robot server in Australia doesn't work because the network latency is too high and the NetShell commands timeout.

2.4.2.2 Radcon (RADNET Console)

The RADNET Console utility is for standard I/O with the robot. All output written with the robot API function **`write_port(NET, … )`** will appear on the RADNET console. Also any keyboard input to **`radcon`** can be read via the robot command **`read_port(NET, … )`**. The console also displays upload/download progress indicators and robot status messages. The status of the robot link is also display when it is lost or re-established. Usage:

```
radcon [ -r  RobotNumber (default 0 = FLO)
         -s  LinkServer_Machine_Host_Name (default terumi) ]
```

2.4.2.3 DLoad

`dload` (Download) is a simple utility for downloading an OS/9 module from the host to the robot, just as the **`remote`** 'd' command. It will overwrite any existing module with the same name. It's just a convenience utility to save starting and exiting **`remote`** just to download a module. Usage:

```
dload [-r <robot> -s <RADNET server host> ] <module file>
```

2.4.3 The RADNET link server

The RADNET link server is the component of the network system that manages the link layer and network layer on the UNIX host side. One RADNET link server (the **`RADNET`** program) must be executing for each robot link. It executes on a host that is physically connected to a radio modem via the host serial port. Only one server may execute on any single UNIX host[30]. The server listens in a pre-defined socket for connections from RADNET clients (on UNIX, Windows '95 or VxWorks). Once a client has established a connection to a server it may send datagrams to the server and the server will route them to either it's robot, another server or another client. Clients are able to nominate a number of port numbers on which they wish to listen. If a datagram packet is received by a server destined for a particular host, a client executing on the specific host and listening on the appropriate port number will be send the datagram. If no clients are listening on the specified port on the addressed machine, the packet is simply discarded. Hence on any one host there should be only a single client listening on any particular port number. Datagrams are addressed by an *IP number, Port number* pair. Client applications need not worry about the interface to a RADNET link server directly as a client API library is available that abstracts the interaction and it is documented below.

[30] This is because the server uses a pre-defined socket on which to listen for client connections. If two servers were executing on the same host, one would be unable to use the socket.

The **radnet** program is invoked from the UNIX command line as follows:

radnet [-p port] [-d] [-b baud]

The options are:

- -p The serial tty on which the radio modem is connected. (default **/dev/ttyb**)
- -b The baud rate. (default 9600)
- -d Show debugging information. (default off) - This shows a hex dump of incoming and outgoing packets.

The **radnet** program will usually be set to run permanently in the background, and only need be restarted if the machine is rebooted or it crashes. This can be accomplished by the following command:

nohup radnet &

In this case all output will be directed to a file (for zsh '**nohup.out**').

2.4.4 Client API - Robot side

The API can be divided into two parts. These correspond to the two layers of the protocol stack - the network layer (**network** module) and the link layer (**netlink** module). The datagram services are provided by the network layer. This API provides a facility to send and receive unreliable datagram packets between any two clients addressed using an *IP* number and a *Port* number. The network layer uses the services provided by the link layer, which are also directly available via the RawDatagram API which can be used to inject or extract raw packets at the link layer level. This is usually used only for debugging the networking software.

```
int SendDatagram(int Dest, int Port, char *Data, int Length,
          int BlockingMode)
```

Description:

This is called to send a datagram packet specified by the **Data** and **Length** parameters, to a destination client specified by the **Dest** IP address and **Port**[31] number.

Parameters:

`Dest` The IP Address of the machine on which the receiving client is executing. Other robots have special addresses denoted by:

`ADDR_ROBOT1`, **`ADDR_ROBOT2`**, etc.[32] for robots.
`ADDR_VISION` - for the vision system.
`ADDR_HOST` - for the host the robot is directly connected to.
The type is an unsigned 4 byte integer, each byte represents a component of the standard 4 component IP address **`a.b.c.d`**.

`Port` The Port number you wish to send the datagram to, in the range [1..2^{16}-1]. Do not use and special port numbers defined in the **`net_usr.h`** header.

`Data` A pointer to a buffer containing the packet data to be sent.

`Length` A count of the number of bytes in the buffer to be sent. All packets much be of even length.

`BlockingMode` One of the values **`BLOCKING`** or **`NONBLOCKING`**. If a packet is send in blocking mode the call will not return until the packet has been queued. This does not guarantee delivery. If the send buffer is full the call will not return until it has emptied enough to queue the packet. In nonblocking mode the call will return immediately but the packet may be discarded if the send buffer is full.

Return:

If NONBLOCKING mode returns 0, in BLOCKING mode return 0 for success.

[31] Note that although RADNET uses IP addresses for host addressing, the Ports are *NOT* TCP/IP port numbers.

[32] These have synonyms for the Wollongong robots which are **`ADDR_FLO`** and **`ADDR_JOH`**.

`int ReceiveDatagram(int *Src, int Port, char *Data, int *Length, int BlockingMode)`

Description:

This function receives a datagram from the specified **Port** and returns the IP address of the machine on which the sending client is executing in **`Src`**. The received data packet's length in bytes is returned.

Parameters:

`Src` A pointer to a variable that upon return will contain the IP address of the machine on which the sending client is executing.

`Port` The Port number you wish to receive the datagram from, in the range $[1..2^{16}-1]$.

`Data` A pointer to a buffer large enough to contain the packet data to be received. The length of the buffer should be specified as the initial value of the variable **Length**. The packet will be truncated if it is too large for the buffer.

`Length` A pointer to a variable into which the received packet byte count will be placed. All packets are of even length. The variable should initially contain the buffer size. The packet will be truncated to this size if it is too large. The buffer size should also be even. **NB**: *Failure to initialise this variable is a common error and often results in unpredictable behaviour.*

`BlockingMode` One of the values **`BLOCKING`** or **`NONBLOCKING`**. If in **`BLOCKING`** mode the call will not return until a packet has been received from the specified **Port** and read into the buffer. If in NONBLOCKING mode the call will return immediately. If a packet was available for the port it will be returned in the buffer, if no packet was available an empty packet is returned (**Length** is set to 0 and the buffer is not written).

Return:

On Success returns 0.

int PeekDatagram(int *Src, int Port, char *Data, int *Length,
int BlockingMode)

Description:

This function is identical to **RecieveDatagram()** except that the read packet is not removed from the network receive queue. Hence it may be repeatedly *Peek'd* or subsequently *Receive'd*.

Parameters: As above.

Return: As above.

---

int SelectPort(int NoPorts, pt_set *PortSet, int TimeOut)[33]

Description:

This function allows a process or thread to block while waiting for input from a number of ports simultaneously. It is similar in concept to the UNIX **select()** call but only for input. It uses a datatype **pt_set** which represents a set of port numbers on which your process wishes to block. A **pt_set** is large and so should be used sparingly and always allocated from the heap. See **PT_ZERO()**, **PT_SET()**, **PT_CLR()** and **PT_ISSET()** below[34].

Parameters:

NoPorts	The maximum port number used in the PortSet.
PortSet	A pointer to a **pt_set** which contains a set of port numbers on which the caller wishes to wait. On return the set will contain only those ports on which data is ready to read using **ReceiveDatagram()**, hence the set must be reset on each call.
Timeout	The number of 100ths of a second after which the call will return if no ports have data ready for reading. In this case the port set will be empty and 0 will be returned.

Return:

The number of ports ready for reading (number of elements in the port set upon return). If a timeout occurred 0 is returned. A return of -1 indicates an error.

---

[33] As of July/1996 the **SelectPort()** function was not fully implemented. Use **PeekDatagram()** on the relevant ports instead. Use a delay to ensure your thread does not busy-wait poll and tie up the CPU.

[34] Note that while **PT_ZERO()** is a function, **PT_SET()**, **PT_CLR()** and **PT_ISSET()** are C Macro's defined in the **net_usr.h** header file.

`PT_ZERO(pt_set *PortSet)`

Description:

Assigns **`PortSet`** to the empty set. That is, clears all elements from the set leaving it empty.

Parameters:

`PortSet`	A pointer to the port set to be cleared. Note that this call doesn't allocate storage - you much do this before calling this function.

Return:

None.

`PT_SET(int Port, pt_set *PortSet)`

Description:

Adds a port to the port set.

Parameters:

`PortSet`	A pointer to the port set.
Port	The port number to add to the set.

Return:

None.

`PT_CLR(int Port, pt_set *PortSet)`

Description:

Removes a port from the port set.

Parameters:

`PortSet`	A pointer to the port set.
Port	The port number to remove from the set.

Return:

None.

```
int PT_ISSET(int Port, pt_set *PortSet)
```

Description:

Determines if a port is in the port set.

Parameters:

PortSet A pointer to the port set.

Port The port number in which to test membership of the port set.

Return:

Returns a boolean value, **TRUE** if the **Port** was in the **PortSet**, **FALSE** if not.

```
int PutRawPacket(SHORT protocol, char *Data, int Length,
                 int BlockingMode)
```

Description:

This call will insert the specified data packet into the link layer hence bypassing the network layer. It may be used for testing or for sending packets using a different protocol than used by the network layer.[35]

Parameters:

protocol Currently one of **PRAW_DGRAM**, **PSOCK_DGRAM** - used for normal packets by the link layer, **PSOCK_STREAM** - for future implementation of stream connections, **PKEEP_ALIVE** - used by the link layer to periodically check the modem connection is still available or a user specified value. See the **net_usr.h** header file.

Data The address of data buffer containing **Length** bytes to be sent.

Length The number of bytes from the buffer to send.

BlockingMode As above for **SendDatagram()**.

Return:

Returns 0 for Success, or a non-zero error code.

[35] The current implementation of the UNIX host end software will display a hex dump of the any received packet who's protocol is unknown.

**int GetRawPacket(SHORT *protocol, char *Data, int *Length,
int BlockingMode)**

Description:

This call will read the next available packet from the link layer receive queue. Note that if the network layer is running you will not be able to obtain all incoming packets over the link with this call because you will be competing with the network layer which also uses this service.

Parameters:

protocol	Upon return this will contain the protocol of the read packet as described above.
Data	The address of a buffer large enough to store the incoming packet.
Length	The address of an integer into which the number of bytes read from the link will be stored (the packet size). Initially this **must** contain the size of the buffer. If the packet is larger that this specified size it will be truncated.
BlockingMode	As above for **GetDatagram()**.

Return:

Returns 0 for Success, or a non-zero error code.

**int PeekRawPacket(SHORT *protocol, char *Data, int *Length,
int BlockingMode)**

Description:

This function is identical to **RecieveRawPacket()** except that the read packet is not removed from the link layer receive queue. Hence it may be repeatedly *Peek'd* or subsequently *Receive'd*.

Parameters: As Above.

Return: As Above.

2.4.5 Client API - UNIX side

The UNIX side Client API is a set of functions to allow UNIX programs to communicate among themselves and client programs executing on a number of Yamabico robots connected into the RADNET network via radio modems. The API is divided into two portions, the *Communication* API and the *NetShell* API. The Communication API provides an unreliable datagram service and is similar to it's corresponding robot side client API documented above. The NetShell API provides additional functions for managing robot software development. The client API is available to C or C++ UNIX programs as a link library. Simply include the **`client.h`** header file and link to the **`client.o`** object file.

2.4.5.1 Communication

The API available to UNIX programs for communication with robots and other RADNET clients is similar, but not identical, to the API available on the robot side[36].

```
int OpenConnection(LONG ServerAddr, char *ServerName,
                   LONG Port)
```

Description:

Before using the **`SendDatagram()`** or **`ReceiveDatagram()`** functions a client must open a connection to a RADNET link server and establish the Port(s) on which it wishes to receive datagrams. **`OpenConnection()`** may be called a multiple times to open connections for receiving datagrams on multiple ports. Each call should be matched with a corresponding **`CloseConnection()`** before the client terminates (or when it no longer wishes to receive datagrams on the given port). Note that at least one port connection must be open before calling **`SendDatagram()`** - although the port number is irrelevant. Note also that any given client can only have connections to **one** RADNET link server, so all calls to **`OpenConnection()`** must specify the same server.

Parameters:

`ServerAddr` This parameter is used to specify the IP number of the RADNET link server this client will connect to. If the IP number is unknown, set this parameter to 0 and specify the string host name in **`ServerName`** instead.

`ServerName` This parameter specifies the host name of the RADNET link server this client will connect to. This should be set to NULL if the IP address was specified in **`ServerAddr`** instead.

---

[36] The Communication portion of the client API is also available under the VxWorks operating system (used in the Fujitsu Vision system at the ANU Canberra).

Port The Port number on which you wish to receive datagrams, in the range [1..2^{16}-1]. Do not use and special port numbers defined in the **net_usr.h** header.

Return:

-1 on error, else the UNIX file descriptor (socket number) associated with this connection.

---

int CloseConnection(int Port)

Description:

This is called to close a connection opened with **OpenConnection()**.

Parameters:

Port The Port number that was passed to the matching **OpenConnection()** call.

Return:

0 for success, or -1 if the specified **Port** was never opened (or already closed).

`int SendDatagram(LONG Dest, LONG Port, void *Data, int Length)`

Description:

This is called to send a datagram packet specified by the **Data** and **Length** parameters, to a destination client specified by the **Dest** IP address and **Port** number.

Parameters:

`Dest`	The IP Address of the machine on which the receiving client is executing. Robots have special addresses denoted by: **`ADDR_ROBOT1`**, **`ADDR_ROBOT2`**, etc. for robots. **`ADDR_VISION`** - for the vision system. **`ADDR_HOST`** - for the host the robot is directly connected to. The type is an unsigned 4 byte integer, each byte represents a component of the standard 4 component IP address **`a.b.c.d`**.
`Port`	The Port number you wish to send the datagram to, in the range [1..2^{16}-1]. Do not use and special port numbers defined in the **`net_usr.h`** header.
`Data`	A pointer to a buffer containing the packet data to be sent.
`Length`	A count of the number of bytes in the buffer to be sent. All packets much be of even length.

Return:

-1 on error, or 0 for success.

`int ReceiveDatagram(LONG *Src, LONG Port, void *Data,`
`int *Length, long timeout_sec=0,`
`long timeout_usec=0)`

Description:

This function receives a datagram from the specified **Port** and returns the IP address of the machine on which the sending client is executing in **`Src`**. The received data packet's length in bytes is returned. It is not possible to receive data on a Port that has not been previously opened with **`OpenConnection()`**. This call will block until data on the specified port is available or the timeout period elapses (if non-zero).

Parameters:

`Src`	A pointer to a variable that upon return will contain the IP address of the machine on which the sending client is executing.

`Port` The Port number you wish to receive the datagram from, in the range $[1..2^{16}-1]$.

`Data` A pointer to a buffer large enough to contain the packet data to be received. The length of the buffer should be specified as the initial value of the variable **Length**. The packet will be truncated if it is too large for the buffer.

`Length` A pointer to a variable into which the received packet byte count will be placed. All packets are of even length. The variable should initially contain the buffer size. The packet will be truncated to this size if it is too large. The buffer size should also be even. **NB**: *Failure to initialise this variable is a common error and often results in unpredictable behaviour.*

`timeout_sec`[37] A timeout period in seconds, upon which the call will return if no data is available. If both **`timeout_sec`** and **`timeout_usec`** are 0 the call will block indefinitely or until data becomes available.

`timeout_usec` A timeout period in micro-seconds. The call will return after the specified seconds and micro-seconds if no data is available. If both **`timeout_sec`** and **`timeout_usec`** are 0 the call will block indefinitely or until data becomes available.

Return:

0 for success, -1 on error or 1 if a timeout occurred.

---

[37] The timeout parameters are optional under C++ on UNIX, but the C version of the API under VxWorks requires 0's be supplied if no timeout period is required.

`int PortFd(LONG Port)`

Description:

This function can be used to obtain the UNIX file descriptor (socket number) associated with the specified Port. Since the current implementation of the API provides no **`SelectPort()`** call, the client can use this function if waiting on multiple ports is required. The UNIX select() system call can be used on the file descriptors returned as an alternative to polling the ports with **`ReceiveDatagram()`** and a timeout. The **`OpenConnection()`** function also returns such a file descriptor.

Parameters:

`Port`	The Port number already opened using **`OpenConnection()`**.

Return:

-1 on error (if the **`Port`** was not open), or the UNIX file descriptor of the associated socket.

2.4.5.2 NetShell

This portion of the API provides services that are ultimately carried out by the ***NetShell*** module on the Yamabico. Services such as upload and download of executable and data modules, execution and unlinking of modules. A list of modules in the robot's memory as well as memory status and the process table can be output to standard output. It also provides the ability to execute any *Spur* locomotion command or ultrasonic sensor command directly from the client program. These services are also used by the user utility programs **`remote`**, **`radcon`** and **`dload`**, which are documented above.

`int SetCurrentRobot(int Address)`

Description:

This function **must** be called before any *NetShell* commands are issued to specify which robot subsequent commands will be addressed to. It may be called any number of times to change the currently addressed robot. Before client termination, **`CloseConnection()`** should be called (only once even if **`SetCurrentRobot()`** is called multiple times). Pass **`CloseConnection()`** the port number returned by this function.

Parameters:

`Address`	The (*special*) IP address of the robot (e.g. **`ADDR_ROBOT1`** or **`ADDR_FLO`**, **`ADDR_JOH`** etc.). Note that if the address specified is not a robot, the NetShell commands will block for ever awaiting a reply (other clients usually don't listen for NetShell commands on the NetShell port).

Return:

-1 if a connection to the RADNET link server could not be established, or the NetShell port number otherwise. This port number should be passed to **`CloseConnection()`**.

SetServer(char *ServerHostName)

Description:

This function can be used to change the default RADNET link server host[38]. It may be called before a call to **SetCurrentRobot()**.

Parameters:

ServerHostName A C string containing the UNIX host name of the machine which is executing a RADNET link server.

Return: None.

FlushInputQueue()

Description:

This is used to discard any packets received back from NetShell. Some times, due to fact that datagrams are unreliable, or if the robot CPU is heavily loaded, the NetShell commands issued from the client timeout. If after the timeout a reply is finally sent, it will be stay in the input queue and will cause the communication to be out of synchronisation. If strange behaviour results when using the NetShell API - try using this call, and check for robot CPU overload or other factors that could cause large network latency.

Parameters: None.

Return: None.

[38] **Please Note:** The current default is the Wollongong machine "terumi.cs.uow.edu.au". If you are at a geographic location other than Wollongong and forget to call **SetServer()** before **SetCurrentRobot()**, the software will quite happily connect to *terumi* and issue commands to the Wollongong robots (if they happen to be powered on). If this is not what was intended you may be left wondering where the commands are going!

`int NetShellAreYouThere(char *RobotName)`

Description:

Check if the **NetShell** module on the robot can be contacted, hence if the link is operational and all networking software is running. This function can also be used just to retrieve the ASCII string name of the robot.

Parameters:

`RobotName`	A pointer to a string buffer that will hold the name of the robot on return if NetShell could be contacted. The buffer should be at least 32 characters.

Return:

The IP address of the robot, or 0 if not contacted (**`ADDR_NONE`**).

```
int MOSRA_Execute(char *ModuleName, int pid=0,
                  int priority=0x70)
```

Description:

Starts the execution of a MOSRA executable module on the robot.

Parameters:

`ModuleName`	The module name on the robot to execute.
`pid`	Preferred Process ID (PID), or 0 for any. (omit under C++ for any)
`priority`	The preferred process priority, 0x70 is normal (omit under C++ for the default 0x70).

Return:

The PID of the started module, or 0 if not found.

`int MOSRA_Upload(char *FileName)`

Description:

Uploads an OS/9 robot module from the robot to the host on which the client is executing. The module will be placed in a file in the current directory with the same name as the robot module.

Parameters:

`FileName`	The module name of an OS/9 executable or data module currently on the robot. The upload progress will be displayed on standard output (and sent to **`radcon`**).

Return:

The size of the module in bytes, or 0 if the module was not found or a network error occurred during the upload (which causes an abort).

`MOSRA_Download(char *FileName)`

Description:

Downloads an OS/9 robot module from the host on which the client is executing to the robot. The module file should be in the current directory.

Parameters:

`FileName`	The UNIX file name of a valid OS/9 robot module. This should **NOT** include the path name (change directory first if necessary). This name will be the module name on the robot after a successful download. The download progress will be displayed on standard output (and sent to **`radcon`**).

Return: None.

`MOSRA_Reset()`

Description:

This function causes a software reset of the master module on the robot. After issuing this command the network connection to the robot will be lost until it finishes rebooting.

Parameters: None.

Return: None.

`int MOSRA_Unlink(char *ModuleName, int ModNum)`

Description:

This removes the specified robot module from the robot's memory. The module may be specified by name **or** number.

Parameters:

`ModuleName`	The module name of an OS/9 executable or data module currently on the robot. Set this to **`NULL`** if specifying by module number instead.
`ModNum`	The module number of an OS/9 executable or data module currently on the robot. Set this to 0 if specifying by module name instead.

Return:

TRUE if module found and unlinked or FALSE if not found.

`MOSRA_ModuleList()`

Description:

Display the list of OS/9 memory modules currently in the robots memory. The list is displayed as a formatted output on standard output.

Parameters: None.

Return: None.

`MOSRA_ProcessList()`

Description:

Display the list of currently executing processes or threads on the robot. The list is displayed as a formatted output on standard output. The output also shows PID numbers, process status and the message source process or semaphore a process is waiting on.

Parameters: None.

Return: None.

`MOSRA_MemStats()`

Description:

Display the robot memory status (free memory and number of fragments). The status is displayed as a formatted output on standard output.

Parameters: None.

Return: None.

`int us_dist(int dir, USDistData *DistData = NULL)`

Description:

Obtains the current distance reading of one or all of the ultrasonic sensors. Supports the old 4 sensor HiSonic Yamabico's and the new 16 sensor HiSonic ring Yamabico's[39].

Parameters:

`dir`	One of **`US_FRONT`**, **`US_BACK`**, **`US_LEFT`**, or **`US_RIGHT`** for the 16 and 4 sensor cases, or an integer sensor number [0…15] for the 16 sensor ring.
`DistData`	If a pointer to a pre-allocated **`USDistData`** struct is supplied, the current distance reading from all 16 sensors is returned in the structure. This only applies to the 16 sensor ring, pass NULL for the 4 sensor case or if the data is not required. The **`USDistData`** struct is defined in the **`client.h`** header file.

Return:

`US_NOECHO` if no obstacle was detected in front of the nominated sensor, or the range reading in cm.

[39] Currently only the 16 sensor ring developed at Wollongong is supported, the 12 sensor ring developed at Tsukuba is not (sorry).

`us_mask(int mask_pattern)`

Description:

Sets the ultrasonic mask pattern. For a 4 sensor HiSonic Yamabico the sensors can be selectively enabled. If using a 16 sensor ring, only turn all the sensors on or off.

Parameters:

`mask_pattern` One of **`US_FMASK`**, **`US_BMASK`**, **`US_LMASK`**, or **`US_RMASK`** for the 4 sensor case, or **`US_NOMASK`** to enable all or **`US_MASKALL`** to diable all for the 4 or 16 sensor case.

Return: None.

Spur locomotion commands

Description:

All **Spur** locomotion commands that are available to robot programs via the **`spurlib.l`** library are also available to UNIX clients. Refer to the Spur documentation, since all function prototypes and behaviour are identical. Note that issuing a Spur command from the client is significantly slower than directly from the robot. Hence this facility should only be used to issue interactive commands, for rapid prototyping of programs, or for testing.

Parameters:

Identical to those described in the Spur documentation.

Return:

Identical to those described in the Spur documentation.

2.5 Inter-module Communication and the Yamabico Bus

The Yamabico Bus is a back plane bus that serves as the communication medium between modules. The architecture is shown in the figure in section 2.1. Communication is between the Master and function modules, never between function modules. The Yamabico Bus hardware is explained in detail in the hardware section and also in [Yam95].

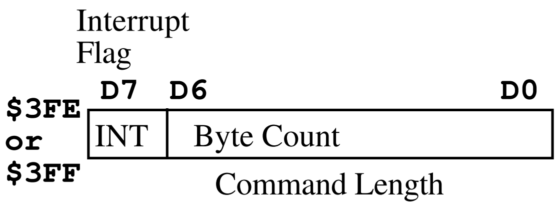
Each of the function modules contains a small amount (1Kbyte) of Dual Port Memory (DPM) that can be addressed directly by the local CPU, and independently by the Master Module CPU over the Yamabico Bus. This shared memory is the basis for communication between the master and function modules. The philosophy of the Yamabico architecture is that the master module directs the function modules by issuing commands and then monitors their progress or state. In accordance with this there are two mechanisms for communication via the DPM. The first mechanism is for sending a command from the master module to the function module with arguments (upto 128 bytes). The second mechanism involves the concept of a *State Information Monitoring Panel* (SIMP). The function modules periodically update a representation of their current state in their respective SIMP's. The user program executing on the master module is then free to interrogate the current state of any function module asynchronously.

Each of the function modules is memory mapped to a specified fixed address in the master module. The address is configurable using DIP switches on the function module boards. The addresses of the standard function modules in the master's address space is defined in the file **`../ys-kit/module/DPM/DPM.h`** and also in [Yam95]. The DPM hardware and protocol is explained in the Hardware documentation folder [Yam95]. The software protocol is reiterated below for completeness. The DPM has two sides, left and right. If data is written into the status register on one side an interrupt signal is generated on the other side. The interrupt is not cleared until the status register on the other side is read. The left side is the function module side and the right side is the master module side. Currently interrupts to the master module are ignored. The DPM is organised as follows:

DPM Address Offset	**Usage**
`$000-$1FF`	**LtoR** SIMP - **`wt_SIP16()`** and **`rd_SIP16()`**
`$200-$2FF`	Not used (**RtoL** SIMP)
`$300-$37F`	**RtoL** Data area for command communication - **`send_com16()`**
`$380-$3FD`	**LtoR** Data for command reply - **`send_reply16()`** (*rarely used*)
`$3FE`	**RtoL** Status register (*interrupt occurs on left side*)
`$3FF`	**LtoR** Status register (*interrupt occurs on right side*)

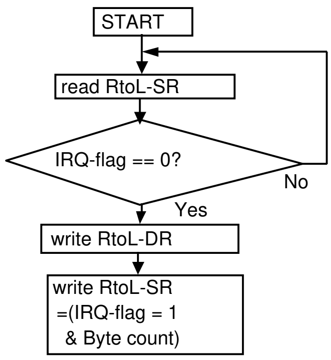
Dual Port Memory Usage Map

The DPM has two sides, Left and Right. If data is written into the status register on one side an interrupt signal is generated on the other side. The interrupt is not cleared until the status register on the other side is read. The left side is the function module side and the right side is the master module side. Currently interrupts to the master module are ignored. The most significant bit (MSB) of the last two addresses in the DPM ($3FE and $3FF) are interrupt flags for the Right-to-Left and Left-to-Right sides respectively. The lower 7 bits of these registers is used as a byte count for the command communication, since no interrupts are required for the SIMP communication model.



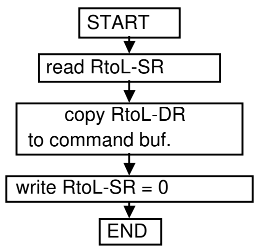
Structure of the status register

If the master module wishes to send a command to a function module it uses the **`send_com16(module,argc,argv)`** function. This function and the other functions discussed below are implemented in the source directory **`../ys-kit/module/DPM`**. The protocol used by this function is as follows:



Protocol for Master to Function module command send.

The writing into the RtoL status register triggers an interrupt on the function module, which is vectored to an interrupt routine that reads the command and clears the status register before processing the command.



Protocol for Function module interrupt routine.

If function module code wishes to write into it's SIMP it uses the **wt_SIP16()** function. This may trigger an interrupt on the master module CPU, but it is usually ignored[40]. The master module may examine the current state of a function module at any time by reading the DPM using the **rd_SIP16()** function.

2.5.1 Case study - The Locomotion Module

This section describes the implementation of communication between the master module and the locomotion module specifically. Some background knowledge from the locomotion module implementation is assumed.

The software that executes on the locomotion module is names *Spur*. User programs executing on the master module make calls to a number of available Spur commands. Refer to the Spur API section for a list of these calls. For the remainder of this discussion just two Spur commands will be considered. Namely the **Spur_line_GL()** and **Spur_get_pos_GL()** functions. These are representative of Spur commands because they represent to two communication mechanisms discussed above. The Spur_line_GL command sends a command to the locomotion module but returns no information to the user program, while the Spur_get_pos command requests information from the SIMP without effecting Spur's current state.

The Spur source code is located in the directory **../ys-kit/module/Spur-16**. When a user program on the master module calls the **Spur_line_GL()** function it is calling a stub function that is statically linked with the user program at compile time. The implementation is in the **Spurlib.l** library. The source for this stub function is in the **lib_source** directory and looks as follows:

```
_line_GL(x,y,th)
int x,y,th;
{
    comma[0] = Spur_LINE_GL;
    comma[1] = x<<8;
    comma[2] = y<<8;
    comma[3] = th*IN_DEGREE;
    send_com16(DPM_ADDR,16,comma);
    count_msec(10);
}
```

Each of the Spur command has an associated numeric command code. These are defined in the **../defs/command.h** header file. In this case the code is placing the command code and required arguments into an array **comma[]**. The code then invokes the **send_com16()** function discussed above to write the 16 bytes of data (4 long words) into the locomotion DPM, hence causing an interrupt on the locomotion module board. The header file defines **DPM_ADDR** as the base address for the locomotion module's DPM. This is typical of the implementation of command type Spur functions.

Next, the interrupt on the locomotion module is vectored to the following interrupt service routine (**../module/dpmirq.c**).

[40]On some Yamabico Robots this interrupt line on the Yamabico Bus II has been cut.

```
dpmirq()
{
    int leng;
    char c;

    c = dpm->mast_csr;
    leng = c;
    leng &= 0X007F;
    rd_dr(leng);

    com_ana();
}
```

In this case the dpm variable is an instance of the structure **`dpm_str`** defined in **`../DPM/DPM.h`**. This structure has members corresponding to the address usage map in the table above. The **`mast_csr`** member is the master to function module status register. The code extracts the number of bytes in the sent command and then calls **`rd_dr()`** with the length. The **`rd_dr()`** function read the specified number of data bytes from the DPM into the **`command[]`** array. Next, **`dpmirq()`** calls **`com_ana()`** (command analyse). The **`com_ana()`** source looks as follows:

```
com_ana()
{
    switch(command[0]) {
.....
          case Spur_LINE_GL: line_GL_com();                break;
          case Spur_LINE_LC: line_LC_com();                break;
          case Spur_LINE_FS: line_FS_com();                break;

          case Spur_ARC_C_GL: arc_c_GL_com();                break;
          case Spur_ARC_C_LC: arc_c_LC_com();                break;
.....
          case Spur_SET_GL_ON_GL: set_GL_on_GL_com();                break;

          default: break;
        }
    clear_sr();
}
```

Which clearly calls the **`line_GL_com()`** function in the case of the Spur_LINE_GL command. This function processes the new trajectory command and then returns. Next the **`com_ana()`** function calls **`clear_sr()`**, which simply clears the status register. This clears the interrupt and also indicates to the master module's **`send_com16()`** function that the DPM is no longer busy and may be written into again.

The Spur software maintains a current state or mode at all times. The commands from the master module simply modify this mode hence changing the tracking behaviour. The mode is maintained in the **`cmode`** variable. The implementation of **`line_GL_com()`** is as follows (**`../module/command_line.c`**):

```
line_GL_com()
{
    int temp,xl,yl,thl;

    temp = command[3] - lo_th_org_in;
    thl = mul444(temp,DELTA_T);
    xl = command[1] - lo_x_org;
    yl = command[2] - lo_y_org;
    trans_cood(xl,yl,lo_th_org,&xl,&yl);
    cmode.para.line_para.x_org = xl;
    cmode.para.line_para.y_org = yl;
    cmode.para.line_para.th_org = cal_ang(thl);
    cmode.mode = LINE_MODE;

}
```

The main thing to notice here is that the function uses the arguments supplied in the **command[]** array and changes the current mode (**cmode**) variable. This concludes the processing that occurs as a result of the DPM interrupt.

The main loop of the Spur software uses the current mode to adjust the tracking and control the motor hardware using feedback from the wheel shaft encoders. The Spur software is driven by hardware interrupts every 5ms which are vectored to the **timirq()** service routine in **../module/timirq.c**. This in turn calls **fb_ctl()** which calls **cal_r_vel()** to calculate the robot velocity and also the **mode_ctl()** function which does a switch statement based on the current mode (**mode_ctl.c**):

```
mode_ctl()
{
    if(cmode.mode == EXP_MODE) do_exp();
    if(cmode.mode == LINE_MODE) do_line_track();
    if(cmode.mode == STOP_MODE) do_stop();
    if(cmode.mode == ACCEL_MODE) do_accel();
    if(cmode.mode == CIRCLE_MODE) do_circle_track();
}
```

Which in the case of line tracking mode calls **do_line_track()** which implements the line tracking algorithm. Looking back to **fb_ctl()** which, as mentioned, calls **cal_r_vel()** which calculates the robot's velocity:

```
cal_r_vel()
{
    register int temp;
    short *data_ptr;
    w_vel[M_RT] = cnt_var[M_RT]*INV_VELOCITY;
    w_vel[M_LT] = cnt_var[M_LT]*INV_VELOCITY;

....
    gl_th = cal_ang(lo_th_org + lo_th);

    if(w_flag == 0) {
        wt_SIP16((int)(dpm)+0x00,4,&r_vel);       /* write to SIP */
        wt_SIP16((int)(dpm)+0x10,4,&r_angv);
    }
    else if(w_flag == 1) {
        wt_SIP16((int)(dpm)+0x20,4,&lo_x);
        wt_SIP16((int)(dpm)+0x30,4,&lo_y);
        wt_SIP16((int)(dpm)+0x40,4,&lo_th);
    }
    else if(w_flag == 2) {
        wt_SIP16((int)(dpm)+0x50,4,&gl_x);
        wt_SIP16((int)(dpm)+0x60,4,&gl_y);
        wt_SIP16((int)(dpm)+0x70,4,&gl_th);
    }
    if(++w_flag == 3) w_flag = 0;
}
```

This clearly calls the **wt_SIP16()** function to write the current state of the position and velocity variable into the DPM. This data will then become available to the master module to read. Hence the SIMP is updated every 5ms.

Turning back to the master module, if we look at the implementation of the library stub for the **Spur_get_pos_GL()** function we find it simply uses the **rd_SIP16()** function to read the current values from the DPM.

```
_get_pos_GL(x,y,th)
int *x,*y,*th;
{
    int xx,yy,thth;

    rd_SIP16(DPM_ADDR+0x50,4,&xx);
    rd_SIP16(DPM_ADDR+0x60,4,&yy);
    rd_SIP16(DPM_ADDR+0x70,4,&thth);

    *x = xx>>8;
    *y = yy>>8;
    *th = thth/DEGREE;
}
```

In conclusion, this model of communication between the locomotion and master module is typical of other functions modules. For example the HiSonic ultrasonic module uses **rd_SIP()** to retrieve the latest ultrasonic distance reading and uses **send_com()** to send the mask commands to the HiSonic module.

2.6 Software Development

Section 2.5.1 describes how to develop user programs on a UNIX host, compile them, debug them, and download them to a Yamabico robot. The robot simulators are also described. Section 2.5.2 describes how to compile MOSRA and function module implementation code and create ROM files for use with an EPROM programmer.

2.6.1 User program development

The sections to follow are:

- Compilation - Compiling Robol/0 and C programs
- Romance - Downloading and executing code on a robot
- Simulation - Using the (M)AMROS and Marvin robot simulators
- Tools - Other tools and utilities for program development
- Environment - The required UNIX host environment for the development software

2.6.1.1 Compilation

To compile a *Robol/0* or C program type the following from the directory containing the source file. This will use the **MicroWare** 68000 C Cross compiler, hence you will need to execute **robocc** from a Sun3 UNIX machine[41].

robocc –ymbc *myprg*.**rb0**

or

mcc *myprg.c*

This will produce a file called **myprg**. This file can then be downloaded to the robot using the **romanceu** program described below.

[41]In the Wollongong Laboratory use the 'Kanako' machine.

2.6.1.1.1 Example programs

Example source code in *Robol/0* and C can be found in the directory:

`../ys-kit/ydemo`

Some of the examples are:

- **`square.c`** - a naive program that drives the robot in a square (almost[42])
- **`square.rb0`** - a *Robol/0* program to drive the robot in a square.
- **`avoid.rb0`** - A very simple obstacle avoidance demo. Can avoid a cardboard box for example.
- **`UScheck.c`** - Displays the ultrasonic sensor distances every second.

2.6.1.1.2 Robocc & mcc

Robocc is a *Robol/0* to C source translator and compiler driver. After translating your **`myprg.rb0`** file into C (**`myprg.c`**) it invokes **`mcc`**. The **`mcc`** driver invokes the following programs to compile and link the code.

- cc68 - Compiler driver (compile only - no linking)
  - cpp - C preprocessor
  - c68 - C compiler
  - o68 - Optimiser
  - r68 - Produces OS/9 relocatable object files (.r files)
- ml68 - Linker (Produces the final OS/9 object for the robot)

2.6.1.2 Romance

The *romance* software (RObot and MAN's communicating environment) is used to interface the UNIX host with the robot. Hence romance consists of two parts - the UNIX side and the MOSRA (robot) side. The standard **`startup`** module started by MOSRA on robot power-on automatically starts the romance module on the robot. The UNIX side can be started as follows.

`romanceu -p` *`serialdevice`*

Where serialdevice is the UNIX serial port device that is plugged into the robot's serial port. For example:

`romanceu -p /dev/ttya`

---

[42]The program waits until the robot has traversed the full distance of one side of the square before changing the tracking to a line at 90^{o} for the next side. Hence the robot will overshoot on the corners.

The MOSRA side provides some interactive commands for manipulating and downloading/uploading object files to/from the robot. It displays the following menu when started:

```
ROBot and MANs' Communicating Environment
        ROMANCE   ver 1.5a
--------Kernel interface Commands---------
        L : Module directory List
        P : Process information
        I : Interrupt table information
        S : free memory Status
        H : Help
        B : Bye 'kill ROMANCE on Yamabico'
        U : Unlink module (name)
        X : eXecute process (name)
                format := X <module name> [<pid>] [<prio>]
        D : Dump  memory
                format := D <s_adrs> [<count>]
        F : Fill  memory by short
                format := F <s_adr> <e_adr> <data>
        W : Write memory by short
                format := W <s_adr> ( back:'^',skip:CR,end:'.')
     FTF9 : File Transfer from OS9  (F9)
     FTT9 : File Transfer to   OS9  (T9)
     FTFU : File Transfer from UNIX (FU)
     FTTU : File Transfer to   UNIX (TU)
                format := FT** <module name>
       SM : Send Massage
        R : Reset

*
```

So, for example to download your myprg object file to the robot and execute it you would type ('*' is the prompt):

    * **`fu myprg`**

    * **`x myprg`**

If you used the '**`l`**' command to list the current OS/9 memory modules in RAM you would see a module named **`myprg`**.

To quit the **`romanceu`** program on UNIX type **CTRL-C** and then press **Q**.

2.6.1.3 Simulation

During the development of robot programs it is inefficient to run them over and over on the robot for testing their behaviour. A simulation system provides a powerful alternative allowing robot programs to be validated with a much smaller turn around time and without utilising a robot. The following sections describe the AMROS and Marvin simulators. The multiple robot version of AMROS called MAMROS is also mentioned.

2.6.1.3.1 AMROS

The AMROS (*Autonomous Mobile RObot Simulator*) simulator was written in the laboratory in Tsukuba, Japan. It simulates robot programs written in Robol/0 only, not C. It also assumes that only one user robot program is executing, hence the MOSRA process creation calls cannot be used. It also assumes a Robol/0 WAIT loop executes every 50ms. The robot program is compiled to run as a native process on the UNIX host. So the simulation is not quite realistic. AMROS still provides a good idea of a robot program's behaviour. If your program fails on AMROS it will surely fail on the real robot, but if it performs correctly on AMROS it may perform correctly on the robot.

AMROS has also been extended to simulate Multiple robots. For information on Multiple AMROS (MAMROS) refer to [Naum93].

Compiling

To compile your Robol/0 program for use with AMROS you need to use a UNIX host that has the GNU gcc compiler installed[43]. Type the following:

robocc -sim *myprg*.**rb0**

This will compile the source program and produce an executable in your directory called **a.out**. This executable includes the AMROS program and your robot program linked together. Ensure your X Windows **DISPLAY** variable is set and execute **a.out** to run the simulation. The simulator also has the ability to read in map files to represent the environment around the robot. These are **.vm** files and are described in the following section. For example:

a.out -vm roboken91.vm

Would start AMROS with a map of Tsukuba's Roboken Laboratory as it was in 1991. This assumes the map file is in the current directory. A full path may be specified.

Map files

The map files represent the environment as a simple 2D line drawing. The map can also store information about the surface reflectivity for the ultrasonic sensors. The 2D line drawings can be converted from the *Interviews 3.1 IDraw* drawing program files into map files using the utility **id2vm**. The format of vm map files is detailed in an appendix.

2.6.1.3.2 Marvin

The Marvin (*Multiple Autonomous Robot VIrtual eNvironment*) simulator allows the simulation of multiple Yamabico robot in realistic simulation time. It is modular in construction so that sensor and actuator simulation can be added incrementally.

Marvin is still under development in the Wollongong Laboratory. Refer to *Marvin* documentation.

[43]In the Wollongong laboratory use the 'Terumi' machine.

2.6.1.4 Tools

2.6.1.4.1 Robocon

Robocon is a utility to allow the graphical editing of *Robol/0* programs. It displays a graphical representation of the Robol/0 action states and allows them to be manipulated using the mouse and menu's.

It is invoked as follows[44]:

```
robocon myprg.rb0
```

Note that robocon works by embedding information as comments into the Robol/0 source code. Hence you should not edit these comments directly. Also the Robol/0 program must have been initially created with robocon, otherwise the existing action modes will all be placed at the same default location on the robocon display when robocon is used for the first time.

2.6.1.4.2 Roboemon

To be completed.

2.6.1.4.3 Robotra

To be completed.

2.6.1.5 Environment

This section details the environment that must be present on the UNIX host for the software development tools to work correctly. This includes the appropriate installation directories, necessary symbolic links, and environment variables.

To be completed.

[44] In the Wollongong laboratory use the 'Terumi' machine.

2.6.2 Building the Yamabico software

2.6.2.1 Compiling the MOSRA Kernel

To compile the MOSRA kernel for the master module or a function module follow these steps:

1) Edit **both** the files **`Config.h`** and **`Config.a`** in the **`../ys-kit/mosra/config`** directory. Just un-comment the line for the module you wish to build.
2) Change to the **`../ys-kit/mosra/kernel`** directory and type: **`make -f Makefile.sun all`**

This produces a file called **`mosra.rom`** in the **`../kernel/objs`** directory. It consists of some boot code to get the board started and an OS/9 format object module called **`mosra68k`** which is the kernel code. Since the 68000 CPU requires the start of execution vector to in low memory and the Yamabico ROM's typically map into higher memory, the boards contain a circuit that temporarily maps the ROM to address 0 upon reset. So the **`boot`** code contains the initial execution address. The **`mosra.rom`** file is the minimum required to make a ROM to execute MOSRA. When started MOSRA will look for a module named **`startup`**, and if found will **`mfork()`** it. Typically **`startup`** will fork any required modules and then exit (with **`death()`**).

2.6.2.2 Making a Master Module ROM image

A simple master module ROM image would consist of the MOSRA kernel image, a startup module which **`mfork()`**'s **`TIMER`** and **`ROMANCE`**, the **`timer`** module and the **`romance`** module. Other modules may be included in the ROM image as desired. Because MOSRA locates the memory module's by searching memory for them (they begin with a special magic number $4afc), modules may be added to the ROM by simple concatenation. There are a number of different master module configurations represented by subdirectories of **`../ys-kit/module`** beginning with **`mm`**. Suppose we wish to build **`mmW`**[45]. Follow these steps:

1) Build the MOSRA kernel as described in the last section, remembering to configure for the required master module.
2) Change to the **`../ys-kit/module/mmW`** directory and type: **`make -f Makefile.sun all`**

---

[45] The standard master module used by the typical Yamabico is mmKEI. mmW is a modification of mmKEI used in Wollongong that adds the Radio Modem Network (RAD NET) and some minor kernel modifications.

3) Change to the **../ys-kit/module/mmW/rom** directory and type: **cp.mosra** This copies the MOSRA kernel image built in step 1 and the **romance** module into the file **mosra.mmW**

4) Type **make.rom**

   This copies the **mosra.mmW**, **startup** module, **network** module, and **timer** module into the final ROM image file **rom.mmW**.

Next the ROM image **rom.mmW** can be programmed using a ROM programmer. Note that since the ROM is built for a 68000 CPU which has a 16Bit data bus, the ROM will be 16bits wide. This means that the computer driving a ROM programmer must interpret the image as a stream of 16bit words (pairs of bytes). So the CPU of the computer driving the ROM programmer must be of the same endian as the 68000 or the ROM image file must have the endian reversed by swapping byte pairs (for example if the ROM programmer was connected to an Intel 80x86 based computer).

2.6.2.3 Compiling function module code

To be completed. Similar to above, but build an appropriate MOSRA kernel first, then compile the function module code and build a ROM image.

2.6.2.4 Changing robot library code

All functions available to user robot programs come from a set of link libraries that are linked with the final OS/9 executable module after compilation. In many cases these are simple stubs that communicate with a function module via DPM or cause a **TRAP** to the kernel (for system calls). The link libraries can be found in the **../local/os9/yamabico/lib** directory. Some of these libraries are concatenations of smaller libraries for specific parts of the API. OS/9 library modules may be simply concatenated to form larger libraries (using the UNIX **cat** command for example).

The procedure for updating or modifying a library function is best illustrated with an example. The example will show how to modify the **us_dist()** command that obtains a distance range reading from an ultrasonic sensor.

The implementation of the HiSonic library code can be found in the directory **../ys-kit/module/HiSonic/lib**. The function we wish to modify is in the file **us_dist.c**. Suppose we have modified the function, now from the directory re-compile to generate the new **libSONic.l** link library by using the command **make -f Makefile.sun**. Once this is complete change into the directory **../ys-kit/ground/install** and type **makelib** to execute the **makelib** script file. This script concatenates all the link libraries from the various module directories into the **ymbclib.l** link library that is linked into user programs from the **lib** directory. If you wish to actually add another link library to this, modify the script. This is not necessary for this example. This takes care of the modification to the **us_dist()** implementation, and may be all you wished to do.

If in addition to change the implementation you also wished to add some extra definitions or declarations that the user programs will require, you will also need to update the **HiSonic_usr.h** header file that is included into user programs from the **defs** directory (**../local/os9/yamabico/defs/ymbc**). You should **not** edit this file directly as there are two copies of these header files. The original source is usually kept in the module **defs** directory. Change into the directory **../ys-kit/module/HiSonic/defs** where you will find the correct **HiSonic_usr.h** header to edit. Now this modified header should be updated into the OS/9 **defs** directory. This is also achieved using a script from the **../ys-kit/ground/install** directory as with updating the library. Change to this directory and execute the **makedefs** script. This will copy all the header files from their respective module **defs** directories into the OS/9 **defs** directory. That completes necessary the changes. Of course user programs will need to be re-compiled and re-linked to use the updated version of the library function.

2.7 Implementation of a Robot Simulator

This section discusses the implementation of the *AMROS* and *Marvin* robot simulators. Specifically what follows is a brief overview and comparison of how the robot *function module* and *master module* code interacts in three contexts: a *Yamabico* robot, the *AMROS* simulator and the *Marvin* simulator. Then some aspects of the implementation of AMROS and Marvin are discussed.

2.7.1 Overview of Yamabico architecture

The Yamabico robots consist of a collection of single board computers interconnected by a bus (the Yamabico II bus). One of the CPU boards is named the *master module* and it conceptually directs the functions of the remaining *function modules*. The function modules typically implement the function of a particular sensor or actuator system, while the master module executes user level code to implement the higher level behaviour of the robot.

On the Yamabico robots, each of the module boards runs an operating system called *MOSRA*. The user programs that run on the master module have an number of API sets available to them. Specifically, the MOSRA system call API, which is implemented by linking stub routines with the user code, which cause a software TRAP #0 which is then vectored to the MOSRA system call dispatch code. The API sets for accessing each of the function modules are implemented using a set of stub routines which read and write a *Dual Port Memory* (DPM) on the appropriate function module. A write causes an interrupt on the function module CPU board which then triggers the appropriate action. If the user function being called only requires current state information, often the DPM is asynchronously read from the master module without the intervention of the function module, which is just required to periodically update the state information in the DPM. This concept is called a *State Information Monitoring Panel* (SIMP).

As is the case with the *Spur* locomotion module, function module code is often largely interrupt driven, being tied closely with the robot hardware. See *section 2.5* for a detailed explanation of the communication between Spur and the master module. The locomotion algorithms implemented on the Spur locomotion module are driven by interrupts from the hardware and from a timer device that delivers interrupts every 5ms. The algorithms use feedback from the motors and wheel encoders to adjust the motor currents based on the current tracking mode. The tracking mode is only modified by master module commands as issued from user program code. The mode is modified when an interrupt is received from the DPM in response to a write from the master module.

The are a number of ways to implement the simulation of these hardware and software components of a robot.

Execute the module software on the host operating system

The software that is normally compiled for the robot CPU target can be re-compiled to run directly on the simulation host system. This is the approach taken by AMROS. The user program is run directly under UNIX. A link library is provided that matches the API of the library of routines available under the robot environment. These routines call functions in the simulator that interact with a representation of the robot's simulated environment.

Simulate the robot module at a hardware level

The CPU and hardware of the robot can be simulated on the host. The code compiled for the robot target can then be interpreted and any memory accesses to hardware trapped and simulated. The interaction with the simulated environment is then via the simulated sensor and actuator hardware.

A hybrid of the above two approaches

Alternatively a combination of these approaches can be taken. This is the approach taken by the *Marvin* simulator. Marvin interprets the user code targeted for the robot. The MOSRA operating system, however, is not simulated in the current version. Any user code system calls or function module commands can be caught by intercepting TRAP #0 instructions, or accesses to the DPM addresses. The code that normally executes on the Spur locomotion module is executed directly on the UNIX host as in AMROS. The code that normally executes on the ultrasonic function module is not executed at all, but the functionality is simulated directly.

2.7.2 AMROS Implementation

The source code for AMROS is located in the **`../ams-kit`** directory. Under this directory you will find **`ys-amros`** which a duplication of the robot source code from **`../ys-kit`** that will now run directly on the UNIX host. Also there is an **`amros`** directory that contains source code for simulation of the robot's environment and gluing the user code with the simulator. AMROS imposes a few restrictions on user robot code to be simulated. Specifically, it assumes that only one user process is executed on the robot and that many MOSRA system calls are not used. The only MOSRA system calls implemented for simulation are the **`malloc()`** and **`mfree()`** memory management calls and the **`death()`** call. No process, interrupt, memory module management[46] or interprocess communication calls may be used. This is typical of user robot code.

---

[46] AMROS does construct a module directory and implements the MOSRA module API calls by maintaining created modules as standard UNIX files. This facility may not be properly supported in the current version and is rarely used in practice. See the **`../ams-kit/amros/mosra.c`** file.

2.7.2.1 Implementation of user calls

The next few sections detail how particular user functions available in the robot target environment are implemented when user code is executing on the UNIX host environment linked with AMROS.

The `malloc()` and `mfree()` MOSRA calls

In the robot environment the function stubs that are linked with the user code for these two functions cause a TRAP #0 with the appropriate code so that MOSRA will dispatch to it's implementation the functions. When the user code is instead linked with AMROS the functions are implemented to simply call the equivalent UNIX **`malloc()`** and **`free()`** functions[47]. This means that the simulation places no restrictions on memory usage by user robot code, as it is allocated from the UNIX process's heap space.

The readSRTKEI() and compSRTKEI() calls

These functions are implemented on the robot by simply reading the current value of the free running timer chip hardware. AMROS implements them in **`../ams-kit/ys-amros/ymbclib/srt.c`** by accessing the global function **`get_timer6840()`** which returns a 10ms interval count by accessing the global variable **`t2`** which is incremented by the environment simulation. See the **`../ams-kit/amros/main.c`** file.

The `set_timer()` and `timer_wait()` calls

These are implemented on the robot by using the MOSRA inter-process communication calls to send a message to the TIMER module process. AMROS implements them by again accessing the global simulation time counter (global variable **`t`**) via the **`CLKget_time()`** function. The implementation is contained in the file **`../ams-kit/amros/ymbcfuncs.c.`**

The death() function

This is the only process management MOSRA system call implemented. On the robot is terminates the current process and frees it's static data area and process descriptor. Under AMROS the implementation ends the simulation.

---

[47] Since the UNIX memory allocation function has the same name as the MOSRA one (**`malloc()`**), the function is not redefined by AMROS. AMROS only implements **`mfree()`** to call the UNIX **`free()`** function.

The `write_cons()` and `read_cons()` ROMANCE functions

These two functions are implemented on the robot with link library stubs that use inter-process communication to communicate with the ROMANCE module process. This process in turn uses the serial interface to communicate with the user on the UNIX host. Under AMROS these functions simply call C standard library **`printf()`** and **`scanf()`**.

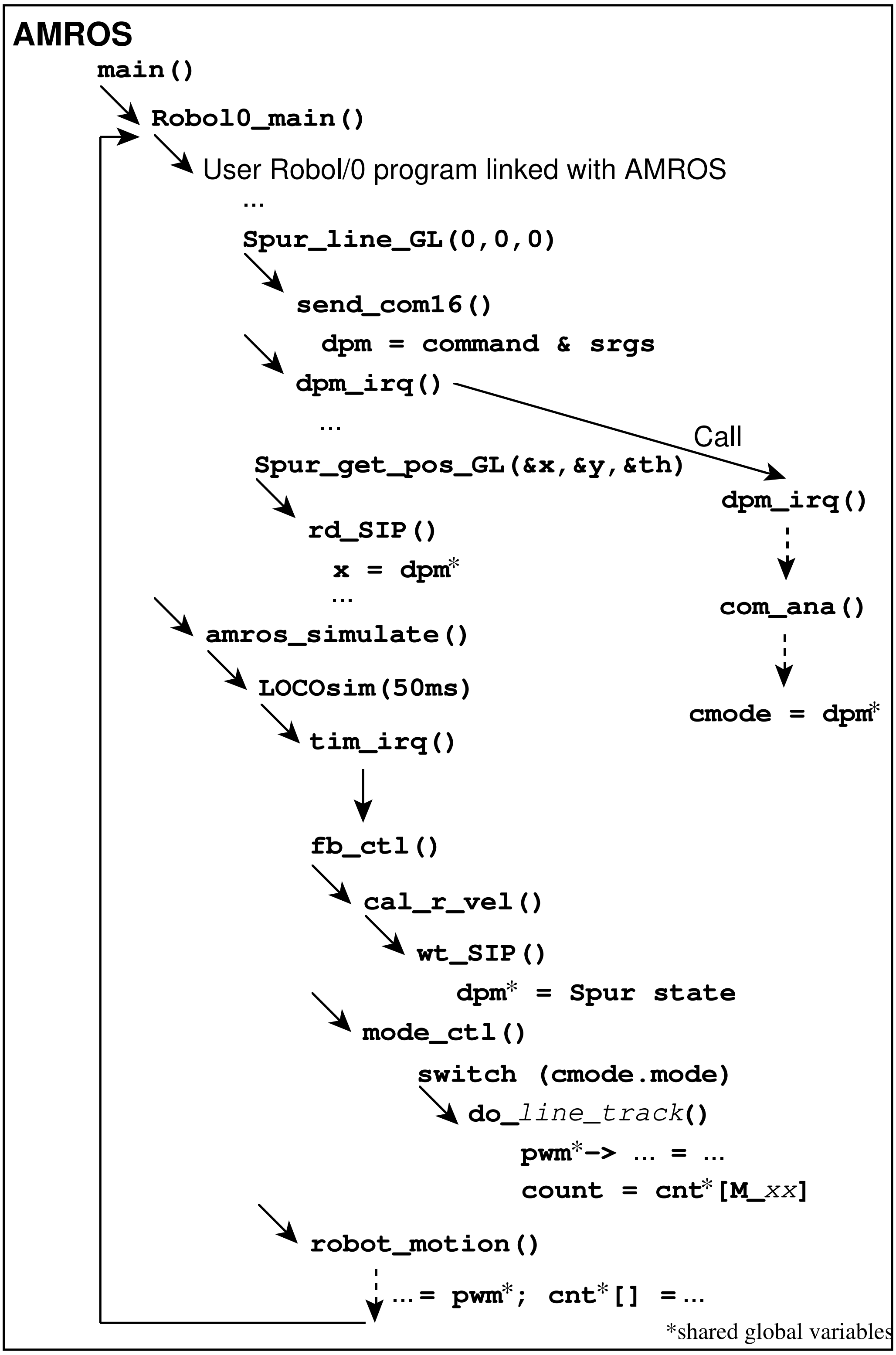
2.7.2.1.1 The UltraSonic module API calls

The HiSonic ultrasonic module is more difficult to simulate. AMROS has adopted a ray line model, where for each firing of the simulated sensor, a fan of rays within -10^{o} - $+10^{o}$ of the sensor direction are traced out until they intersect a surface in the 2D map. The 2D map files contain reflectance and diffusivity data for each surface, which is used to calculate the reflected rays. If the rays eventually reflect back into the sensor, the length of the traced ray is used as the measure of the distance the sensor detects.

The user program on the robot calls the **`us_dist()`** and **`us_mask()`** functions to obtain range data and select the sensors. These functions just read and write the DPM on the HiSonic board. The AMROS implementation for the functions is located in the **`../ams-kit/amros/sensor.c`** file. It directly implements the ray algorithm by accessing the map data structures.

2.7.2.1.2 The Locomotion module Spur API calls

Rather than simulating the locomotion of the robot at a high level as was the case with the ultrasonic sensor simulation, the approach taken is to execute the code that normally executes on the robot's locomotion function module board directly on the UNIX host. The motor and wheel encoder hardware is then simulated and interacts with the Spur locomotion software. Please refer back to the diagram at the end of the Spur implementation section for a summary of how Spur works in the robot environment (*section 2.3.3.2*). The diagram below shows how Spur is executed in AMROS. Compare it with the robot case.



AMROS software implementation

2.7.3 Marvin Implementation

The Marvin simulator is designed to simulate multiple robots more realistically that AMROS. It removes some of the restrictions such as only simulating Robol/0, and only allowing a single user process per robot[48]. Marvin uses an interpreter to execute the Motorola 68000 machine code that executed on the robot itself. Hence it is binary compatible with the robot. A single UNIX process is created for each robot being simulated. These each run a copy of the interpreter an communicate with the main Marvin process using Sockets. The main process manages the user interface, represents the environment and manages the communications between robots. The environment representation is object-oriented and is 3D. This will allow extra sensor simulations to be added in a modular fashion in the future[49]. Marvin uses some of the locomotion and ultrasonic sensor simulation code from AMROS.

2.7.3.1 Implementation of user calls

The next few sections detail how particular user functions available in the robot target environment are implemented when user code is executing under the Marvin interpreter. In the current version of Marvin any MOSRA system calls have to be caught by intercepting the **`TRAP #0`** instruction and simulated. In a future version the operating system executing on the robot master module (MOSRA) will execute under the interpreter.

The `malloc()` and `mfree()` MOSRA calls

In Marvin the **`malloc()`** and **`mfree()`** system calls are caught through **`TRAP #0`** and implemented on the simulated memory array using the MOSRA algorithms.

The `readSRTKEI()` and `compSRTKEI()` calls

These functions are implemented under Marvin by catching memory read/write accesses to the address of the timer chip hardware. The appropriate time it returned based in the number of clock cycles elapsed, which is counted by the interpreter.

The `set_timer()` and `timer_wait()` calls

Marvin intercepts these calls by intercepting the MOSRA **`send_mess()`** system call. It then checks the destination process ID (pid). If the pid is that of the **`TIMER`** process then the calls are simulated.

---

[48]The first implementation of Marvin will only allow a single user process per robot, and will not run MOSRA. Hence not all the MOSRA system calls are available.

[49]It is hoped that vision simulation will be added in the next year.

The death() function

The **`death()`** function sends a terminate message to the main process and ends the interpreter.

The `write_cons()` and `read_cons()` ROMANCE functions

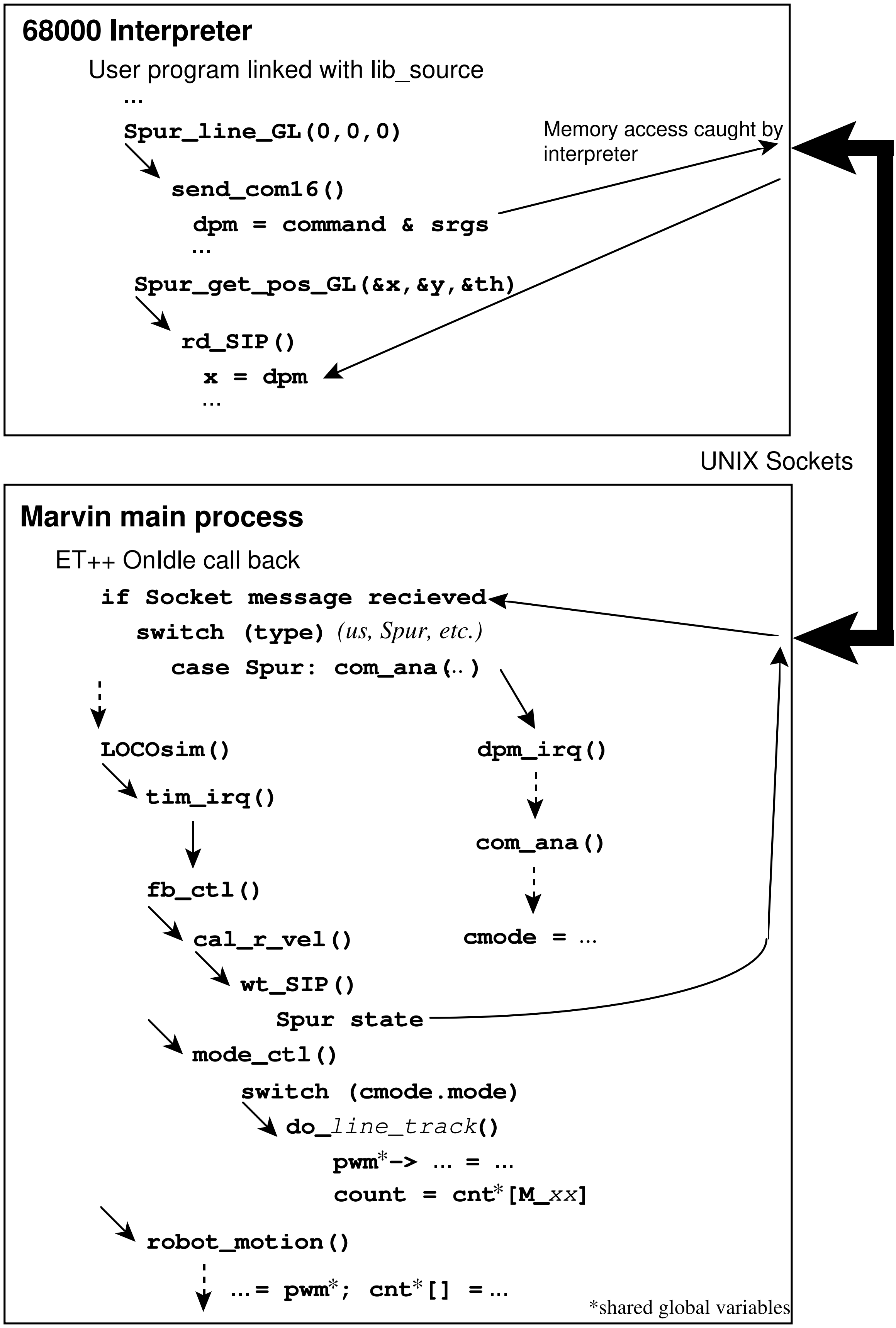
The console I/O calls are handled in a similar way to the timer calls. The user program sends I/O requests to the **`ROMANCE`** process using the MOSRA **`send_mess()`** system call. It is intercepted and if the process ID is that of romance then a message is sent to the main Marvin process to input or output to either standard I/O or a robot window.

2.7.3.1.1 The UltraSonic module API calls

Marvin uses the AMROS ray model to simulate the ultrasonic sensors. The difference is that the environment is represented in 3D in Marvin. The user program on the robot calls the **`us_dist()`** and **`us_mask()`** functions to obtain range data and select the sensors. These functions just read and write the DPM on the HiSonic board. Under Marvin the interpreter can detect and intercept memory accesses to the HiSonic DPM area. It then sends the appropriate messages to the main process where the ray model algorithm is implemented with the environment representation.

2.7.3.1.2 The Locomotion module Spur API calls

Again, Marvin uses the code from AMROS to simulate the locomotion. Both the Spur software that normally executes on the locomotion board and the environment simulation of motors and wheel encoders execute on the main Marvin process. User program Spur calls just read and write to the locomotion DPM, which is intercepted by the interpreter and the command, arguments and results are communicated with the main process via the sockets. The diagram below shows the architecture of Marvin executing a single robot’s code.



Marvin software implementation

2.7.3.2 Marvin multi-robot synchronisation scheme

This section briefly describes the protocol by which Marvin manages the simulation-time synchronisation of multiple robot interpreter processes. As the user code on each robot is simulated independently of the others and of the environment by an interpreter, we need to have a mechanism to manage the synchronisation of their interaction. Consider the following example.

Suppose robot 1 runs it's user program for 10 seconds with no interaction with the environment. Then at 10 seconds it decides to read an ultrasonic sensor. At this point the blackboard needs to simulate the environment up to the 10 second mark before calculating the ultrasonic distance. This involves simulating the locomotion etc. of all of the robots up to 10 seconds. If this were not done, another robot may not be in the correct place when the distance reading is taken (it could be in front of robot 1's sensor, for example). Unfortunately it is not as simple as just advancing the environment simulation up to 10 seconds, because is may be that another robot, say robot 2, will take a sensor reading at 5 seconds, but the interpreter for it is running so slow it's only currently up to 3 seconds and hence has not requested the reading from the blackboard yet. If when it gets to 3 seconds and requests a reading from the blackboard and the environment had already been advanced to 10 seconds the reading would be incorrectly from the robot's future.

The solution to this problem used by Marvin is to use the protocol described here, briefly at first and then in more detail with pseudo code. Basically the simulation is started with all of the robots executing and keeping their own independent simulation time count. When a robot wishes to perform a sensor or actuator command it sends a message to the blackboard process. If results are to be returned, the interpreter is halted, only monitoring messages from the blackboard. If no results are needed the interpreter continues on. The blackboard maintains a sorted queue of requests for 'sensor/actuator commands' received from the robots. Upon receiving a command message the blackboard adds it to the queue sorted on the time the command was issued. It then sends requests to each robot except the originator of the command message, requesting that they 'simulate up-to' **at least** the time the originator's command was issued. It also stores an indication that each robot has replied to the requests. Only after all robots have replied to the 'simulate up-to' request can the environment be simulated up to this time. However, as a result of the other robot processes simulating up-to the requested time, if they were not past it already, they may have sent further 'sensor/actuator command' requests to the blackboard of an earlier time. In this case the same procedure is followed when these are received. When all replied have been received for the message on the queue with the earliest time (since earlier 'sensor/actuator command' requests may have been received), the environment may be advanced to this time and the command removed from the queue.

The robot processes only have to keep a sorted list of the 'simulate up-to' request times they have been requested to simulate up to by the blackboard, so they can reply to each as their simulation time advances past them. The robot processes always continue to simulate unless waiting for data to be returned from a sensor command.

Algorithm for the Robot processes

```
Flag simulating        // Are we executing or waiting for sensor/actuator requests?
Flag terminate         // Have we received a terminate request from the blackboard?
SortedList simulateTo  // Blackboard has requested us to simulate to these times
SimulationTime t       // Current simulation time

simulating = Yes
terminate = No

Do
    If (simulating)
        Interpret one instruction
        If (User code crashes) terminate = Yes

        If (User code executes sensor/actuator command)
            Send request to blackboard
            If (requires a reply) simulating = No

        If (t >= simulateTo[lowset t])
            Remove lowest t from simulateTo list
            Send simulate upto time reply

    If (Received message from blackboard)
        If (Sensor/actuator reply message) simulating = Yes
        If (Terminate request) terminate = Yes
        If (simulate upto time request message)
            If (message.t >= t)
                Send upto time reply immediately
            Else
                Put t on simulateTo list in sorted position

While (not terminate)
```

Algorithm for Main Process (Blackboard)

The main Marvin process is also responsible for implementing the Graphical User Interface (GUI). The GUI is implemented using the *ET++* framework. The socket communications between the main and robot processes was implemented with the *socket++* framework. In order to integrate the input models of ET++ and socket++ it was necessary to implement the main processing of the blackboard inside the ET++ `OnIdle` call-back.

```
Type CommandType is {
        CommandMessage message
        Time time
        Robot fromRobot
        Array of Flags uptoTimeReplied[1..NoRobots]
}


SortedList of CommandType commands  // Queue of commands to be processed
SimulationTime t                    // Current simulation time

OnIdle:
        If (Robot message received)
                switch (message type)
                        case (sensor/actuator command):
                                Add message to commands[] in sorted order by message.time
                                Send simulate uptoTime request messages to all robots*
                                command.uptoTimeReplied[1..NoRobots] = No*
                                        (*except SendingRobot, and except if a robot already
                                          replied to a future uptoTime request)

                        case (simulate uptoTime reply FromRobot):
                                commands[].uptoTimeReplied[FromRobot] = Yes

        If (commands[lowest time].uptoTimeReplied[1..NoRobots] all Yes)
                Simulate environment
                        (for 100ms or up to commands[lowest time].time,
                                                whichever is sooner)
                If (t >= commands[lowest time].time)
                        Process sensor/actuator command commands[lowest time].message
                        Remove commands[lowest time] command from list
```

3. Appendices

3.1 Appendix A - API Prototype Reference

This appendix summarises the API's of MOSRA and some function modules. The function call prototypes are listed below.

3.1.1 MOSRA

Process Control functions

```
int mfork(char *mname,int pid,int priority);
int pcreate(MOD_EXEC *mod_address,int pid,int priority);
int death();
int sleep();
int wakeup(int pid);
int getpid();
char *get_work();
```

Interrupt Handling & Exception functions

```
int irqtbl(int level,IRQTBL *table);
int irqdel(int level,IRQTBL *table);
int irqctl(int pid,int level);
int exsect();
int exend();
int irqset(int level);
int irqrst();
```

Interprocess Communication functions

```
int send_mess(int pid,char *mes_p);
void *recv_mess(int pid);
int test_mess(int pid);
```

Memory Allocation functions

```
void *malloc(int size);
int mfree(void *address);
```

Memory Module functions

```
int ismod(void *m_adr);
MOD_DATA *make_mod(char *mname,int size);
int crcgen(MOD_DATA *m_adr);
MOD_DATA *get_mod(char *mname);
int regmod(MOD_DATA *m_adr);
int delmod(MOD_DATA *m_adr);
```

3.1.2 Miscellaneous

ROMANCE console functions
```
void write_cons(char *form_str,...);
char *read_cons(char *form_str, char *data, int *count);
```

robocc option function
```
void _report_am_name(char *name);
```

Simulator
```
void amros_simulate();
void robol0_main();
```

3.1.3 Function Modules

US Sensor functions
```
int us_dist(int dir);
void us_mask(int mask_pattern);
```

Optical Sensor functions

IS eye functions
```
void ISSUE_FORK(int p_name);
```

IS eye IAS process functions
```
void IAS_thdist(int thdist[256]);
void IAS_dist_cm(int i);
void IAS_change_mode(int mode);
int IAS_active_mode();
void IAS_ld_control(int ld_mode);
```

IS eye PaSS process functions
```
PaSS_index PaSS_can_pass(PaSS_degree,PaSS_index);
PaSS_index PaSS_free_pass(PaSS_degree,PaSS_index,PaSS_index);
PaSS_degree PaSS_find_patchCL(PaSS_degree,PaSS_degree,PaSS_index,int);
PaSS_degree PaSS_find_patchL(PaSS_degree,PaSS_degree,PaSS_index,int);
PaSS_degree PaSS_find_patchCR(PaSS_degree,PaSS_degree,PaSS_index,int);
PaSS_degree PaSS_find_patchR(PaSS_degree,PaSS_degree,PaSS_index,int);
int PaSS_get_dy(PaSS_index,PaSS_degree);
int PaSS_get_x(PaSS_index);
```

Spur functions
```
void Spur_stop_q();
void Spur_stop_Q();
void Spur_spin_GL(int th);
void Spur_spin_LC(int th);
void Spur_spin_FS(int th);
void Spur_set_ang_vel(int angv);
void Spur_set_ang_accel(int alpha);
void Spur_servo();
void Spur_servo_free();
int Spur_near_ang_GL(int ang,int error);
int Spur_near_ang_LC(int ang,int error);
int Spur_near_ang_vel(int angv,int error);
void Spur_line_GL(int x,int y,int th);
void Spur_line_LC(int x,int y,int th);
void Spur_line_FS(int x,int y,int th);
```

```
void Spur_arc_c_GL(int x,int y,int r);
void Spur_arc_c_LC(int x,int y,int r);
void Spur_arc_c_FS(int x,int y,int r);
void Spur_arc_t_GL(int x,int y,int th,int r);
void Spur_arc_t_LC(int x,int y,int th,int r);
void Spur_arc_t_FS(int x,int y,int th,int r);
void Spur_stop_GL(int x,int y,int th);
void Spur_stop_LC(int x,int y,int th);
void Spur_stop_FS(int x,int y,int th);
void Spur_adjust_pos_GL(int x,int y,int th);
void Spur_adjust_pos_LC(int x,int y,int th);
void Spur_adjust_pos_FS(int x,int y,int th);
void Spur_set_LC_on_GL(int x,int y,int th);
void Spur_set_LC_on_LC(int x,int y,int th);
void Spur_set_GL_on_GL(int x,int y,int th);
void Spur_set_pos_GL(int x,int y,int th);
void Spur_set_pos_LC(int x,int y,int th);
void Spur_set_vel(int vel);
void Spur_set_accel(int acc);
void Spur_get_pos_GL(int *x0,int *y0,int *th0);
void Spur_get_pos_LC(int *x,int *y,int *th);
void Spur_get_vel(int *vel,int *angv);
int Spur_near_pos_GL(int xx,int yy,int r);
int Spur_near_pos_LC(int xx,int yy,int r);
int Spur_near_vel(int vel,int error);
int Spur_over_line_GL(int xx,int yy,int th);
int Spur_over_line_LC(int xx,int yy,int th);

void Spur_line_GL_cm(int x,int y,int th);
void Spur_line_LC_cm(int x,int y,int th);
void Spur_line_FS_cm(int x,int y,int th);
void Spur_arc_c_GL_cm(int x,int y,int r);
void Spur_arc_c_LC_cm(int x,int y,int r);
void Spur_arc_c_FS_cm(int x,int y,int r);
void Spur_arc_t_GL_cm(int x,int y,int th,int r);
void Spur_arc_t_LC_cm(int x,int y,int th,int r);
void Spur_arc_t_FS_cm(int x,int y,int th,int r);
void Spur_stop_GL_cm(int x,int y,int th);
void Spur_stop_LC_cm(int x,int y,int th);
void Spur_stop_FS_cm(int x,int y,int th);
void Spur_adjust_pos_GL_cm(int x,int y,int th);
void Spur_adjust_pos_LC_cm(int x,int y,int th);
void Spur_adjust_pos_FS_cm(int x,int y,int th);
void Spur_set_LC_on_GL_cm(int x,int y,int th);
void Spur_set_LC_on_LC_cm(int x,int y,int th);
void Spur_set_GL_on_GL_cm(int x,int y,int th);
void Spur_set_pos_GL_cm(int x,int y,int th);
void Spur_set_pos_LC_cm(int x,int y,int th);
void Spur_set_vel_cm(int vel);
void Spur_set_accel_cm(int acc);
void Spur_get_pos_GL_cm(int *x,int *y,int *th);
void Spur_get_pos_LC_cm(int *x,int *y,int *th);
void Spur_get_vel_cm(int *vel,int *angv);
int Spur_near_pos_GL_cm(int xx,int yy,int r);
int Spur_near_pos_LC_cm(int xx,int yy,int r);
int Spur_near_vel_cm(int vel,int error);
int Spur_over_line_GL_cm(int xx,int yy,int th);
int Spur_over_line_LC_cm(int xx,int yy,int th);
```

Voice functions

```
void voice_init();
void voice_set(int amp, int rate);
void v_boadCHK(int boad);
void sayd(int num);
void sayx(int num);
void says(int num);
void sayw(char *str);
void speakf(char *fmt, int ag1, int ag2, int ag3, int ag4,...,int ag9);
void sayp(char *str);
void say_flush(int thre);
int say_ended(int rest);
```

Timer functions

```
void set_timer(int count);
void timer_wait();
int readSRTKEI();
int compSRTKEI(int t0,int time);
```

3.2 Appendix B - AMROS Map file format

To be written.

3.3 Additional Information

3.3.1 Contacts

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Please contact us if you have any comments, find errors or have suggestions on content.

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3.3.2 World Wide Web (WWW)

The Wollongong laboratory home page has the URL:

http://terumi.cs.uow.edu.au/

The Tsukuba Roboken laboratory home page is:

http://roboken.is.tsukuba.ac.jp/

or

http://130.158.125.241/

3.4 Bibliography

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3.5 Document History

Date	Author	Comment
10/2/95	David Jung	Created initial document, version 0.x Documented Software Section
19/5/95	Ben Stanley	Re-format to MS-Word 6.0 for Windows, added some parts on hardware.
	Ben Stanley	Converted back to Word for the Mac.
27/6/95	David Jung	Fixed formatting lost in conversion.
28/6/95	David Jung	Documented more API calls.
10/7/95	Ben Stanley	Split document into Hardware and Software files.
10/7/95	David Jung	More format fixes. Filled out section on Software Development.
11/7/95	David Jung	Described directory structure. Added MAMROS section.
12/7/95	Ben Stanley	Accidentally **deleted** software documentation!
13/7/95	David Jung	Re-wrote section on Software development and Simulation.
14/7/95	David Jung	Re-wrote and finished Spur API.
2/8/95	David Jung	Added MOSRA Examples.
8/8/95	David Jung	Added more Examples. Corrections.
26/8/95	David Jung	Described MOSRA system calls.
28/8/95	David Jung	Added section 2.4 Inter-module communication.
5/9/95	David Jung	Added Spur examples/diagrams.
12/9/95	David Jung	Documented ROMANCE console implementation, voice API, and locomotion implementation.
13/9/95	David Jung	Documented MOSRA interrupt API, cleaned up Hardware section styles.
13/9/95	Ben Stanley	Cleaned up and added to Hardware section.
14/9/95		**Release 1.0**
1/10/95	David Jung	Added AMROS and Marvin implementation notes.
6/10/95	David Jung	Converted to Word 6.0 and made master document, cleaned up styles, headers, footers etc.
6/10/95	David Jung	Filled out building ROM's section.
7/10/95	David Jung	Finished MOSRA & timer function implementation notes.
8/10/95		**Release 1.1**
10/5/96	David Jung	Corrections to module API and **`sleep()`**, **`wakeup()`**.
2/7/96	David Jung	Documented RADNET Networking.
6/7/96	David Jung	Documented Threads, Semaphores and Whiskers API's.
10/7/96		**Release 1.5**