RESEARCH PORTFOLIO – DESIGNING AN UNMANNED MILITARY RECONNAISSANCE PROTOTYPE USING SYSTEMS ENGINEERING METHODS

Systems Engineering Analysis (ENGN2226)

Prepared by:
James Robertson – u5587290

Due by 14 October 2015

Contents

1. Executive Summary

This report used system analysis techniques to design and produce a prototype unmanned military reconnaissance and patrolling vehicle, and provided future improvements and steps that could be undertaken by the Australian military if it decided to implement such a device. Using analysis methods, a solution was developed that included: view screens and a controller to increase the user's ability to manipulate the robot remotely and a UGV (Unmanned Ground Vehicle) that was 60 cm in height with a camera that could capture 24 FPS and perform image recognition using a 1 GHz Beagle bone processor board. Additionally, the final solution used two Arduino microcontrollers to control three servos and four motors, with a 2 Ah LiPo battery. The main analysis methods used included investigation into qualitative factors using conducted surveys to investigate the ethical consequences of unmanned warfare, quantitative analysis to determine whether the loss of life of soldiers in warfare outweighs the ethical ramifications of unmanned conflict, time factors to consider the amount of processing time required for each action by the system, cost factors to determine the cost-benefit ratio of the system compared to that of a human soldier, human factors to define the best configuration for ease-of-use by the unmanned robot controllers, materials factors to investigate the ideal components of the system, energy factors to determine the effect of the system's manufacturing on the environment and economy and control factors to create the control system used by the unmanned system to make decisions. This final implementation fulfilled all requirements and was an effective design.

2. Introduction

2.1 Problem statement

To design an unmanned ground reconnaissance and patrolling prototype for use in the Australian military.

2.2 Design requirements

The requirements for this design prototype are: (a) it should cost less than $8000 initially, (b) that it cost less than $1000 p.a. in maintenance and training costs, (c) that it be able to recognise and eliminate enemy threats, (d) should be able to run for more than 8 hours, (e) the vehicle should be able to communicate with an operator, (f) that the vehicle be easily constructed out of off-the-shelf components, (g) that the vehicle be as easy to repair as possible and (h) that the vehicle be scalable to larger sizes. These requirements were based on suggestions in *Military robots: mapping the moral landscape* (Galliott 2015) and *Examining the Army's Future Warrior: Force-on-Force simulation of Candidate Technologies* (Randall, Matsumura, Steinberg, Herbert, Kantar & Bogue 2004).

2.3 Motivation

As Russia and China begin to upgrade their respective obsolete military arsenals, Australia is continually falling behind in terms of unmanned military solutions. A lack of military funding and a marginal military industrial complex in Australia have contributed to this shortfall, meaning that for the time being Australia has to source its military hardware from allied countries such as the USA, and hope that a major war does not break out between powerful nations involving Australia. A cheap, easily usable UGV system could go a long way towards improving Australia's current technological disadvantage (Singer 2010).

Unmanned vehicles that can follow, lead and protect soldiers have a number of benefits: according to Newsweek, the number of US soldiers killed in Iraq due to supply convoy raids between 2003 and 2007 was 3,000 (Braw 2014). This is a large proportion of the US total deaths between 2003 and 2011 in Iraq of 4,488. This shows that in a modern asymmetric warfare situation, in which a vastly superior power attacks and occupies a smaller weaker nation, casualties will mostly come from targets of opportunity, like supply convoys. If these supply convoy guards were unmanned, casualties would be greatly reduced and will also have the effect of making the supply convoys harder to raid (Braw 2014). After all, it's harder to sneak up to a highly advanced sensor platform (Gregory 2008). One example of an existing UGV system is the Israeli Guardium, as seen in Figure 1.

Figure 1 – Image of the Israeli border-patrol Guardium vehicle. It has been extremely successful against Hamas insurgents (World Tribune. 2012)

Consequently, it is clear that a UGV system will greatly reduce casualties in both a warzone where one side has a vastly superior military, such as NATO forces vs. Iraqi militants, and also in a warzone where the military balance is more precarious such as Israel's situation with neighbouring Arab states (Galliott 2015). To allow Australia's continued military strength against possible evolving opponents such as China and also insurgencies such as Daesh aka ISIS, Australia should develop its own UGV system.

2.3.1 Conducted surveys to determine public interest

Formal surveys measuring the response of US citizens to this automated warfare have also been conducted. In the book *Governing Lethal Behaviour in Autonomous Robots*, for instance, a survey was performed using a commercial survey company: *SurveyMonkey.com* in 2009 (Arkin 2009). In the survey, the questions included the following five questions:

1. Given that military robots follow the same laws of war and code of conduct as for a human soldier, in which roles and situations is the use of such robots acceptable?
2. What does it mean to behave ethically in warfare?
3. Should robots be able to refuse an order from a human, and what ethical standards should they be held to?
4. Who, and to what extent, is responsible for any lethal errors made?
5. What are the benefits and concerns for use of such robots?
6. Would an emotional component be beneficial for use of such robots?

The results from the survey identified that levels of autonomy should be as follows: "the more the control shifts away from the human the less such an entity is acceptable to the participants, a human soldier was the most acceptable entity in warfare followed by a robot as an extension of the war-fighter, with an fully-autonomous robot being the least acceptable, there is a larger gap in terms of acceptability between a robot as an extension of the war-fighter and autonomous robot then that between soldier and robot as an extension of the war-fighter" (Arkin 2009).

Taking human life by an autonomous robot in both open warfare and covert operations was considered unacceptable to more than half of the participants (56% disagreed or strongly disagreed), especially in the case of covert operations on friendly or home territory. In terms of combat or civilian roles, the survey identified the most tolerable role for using both kinds of robots (as an extension of the 'war-fighter' or autonomous vehicles) as reconnaissance, the least acceptable is for crowd-control. The robots could be acceptable if used for roles where less force is involved, such as for a sentry or for scouting, and should be avoided for roles where the use of force may be necessary (Arkin 2009).

2.3.2 Ethical concerns

However, the future trends in combat are clear, in that warfare will remain and autonomous robots will eventually be deployed in a battlefield situation (Galliott 2015). Thankfully, it is likely, based on the current state of robotics that in the future autonomous robots may be able to have superior performance than humans under these conditions for the following reasons:

1. The ability to act conservatively, in that robots do not need to protect themselves in cases of uncertain target identification. For instance, if a figure moves towards a robot carrying an object in

its hands, the robot will not have a panicked self-preservation response like a human, and could consequently avoid accidently shooting the poor civilian child carrying food home for his family. Autonomous armed robots do not need to have self-preservation as their fundamental drive, after all (Singer 2010).

2. The ongoing development and use of a broad range of robotic sensors better equipped for battlefield observations than humans currently possess (Arkin 2009).

3. They can be designed without emotions that compromise their judgement or result in anger and frustration with ongoing battlefield events. Robots also can be programmed not have a tendency towards cognitive bias, known as ‘scenario fulfilment’, where a human will neglect or distort contradictory information in stressful situations, and only accept information that follows their pre-existing belief patterns (Shaker & Wise 1988).

4. If they are working in a team of combined human soldiers and autonomous vehicles, robots have the potential ability to independently and objectively monitor ethical behaviour in the battlefield for all parties and reporting any ethical violations that they observe. This presence alone might lead to a decrease in human ethical infractions in warfare (Arkin 2009).

5. They can integrate more information from more sources more effectively before responding with lethal force than a human could possibly do in real-time (Singer 2010).

It is quite possible that in the future, based on these details, future descendants will wonder how society functioned without robots, and perhaps label the usage of human soldiers in warfare as ‘barbaric’. It is consequently reasonable to assume that an unmanned reconnaissance vehicle is well within ethical guidelines in regards to warfare.

3. Approach

In determining the optimum solution for this unmanned system, a systems analysis approach must first be taken. The initial step was to define the system boundaries, so that the entire system could be considered, as seen in Table 1.

Table 1 – System boundary table

Internal	**External**	**Outside**
Chassis	Human controller	Other country’s UGV systems
Camera	Local terrain	Other country’s UGV countermeasures
Controlling device	Enemy entity	Future wars
Power source	Human commander	Areas of application
Vehicle cost	Friendly soldiers	Laws regarding robots
Microprocessor controller	Civilian entities	Local weather
Microprocessor programming		
Weaponry loadout		

The system boundaries have shown the parts of the system that can be directly modified or improved, and also the parts of the system that affect the system but cannot be modified. This will be important in defining the use case of the system, so that the external factors can be taken into account when determining the actions of the robot. The use case diagram can be seen in Figure 2.

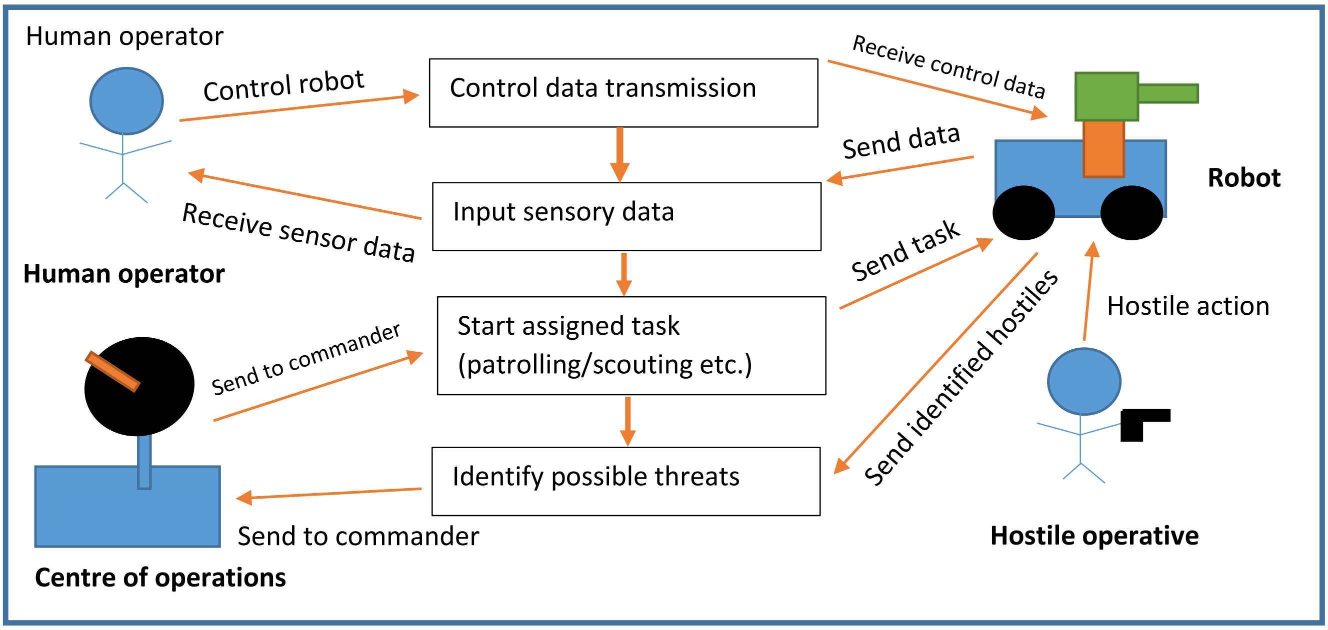


Figure 2 – Use case diagram for system

The next step in defining this system is to decide which solution to use for patrolling and detecting hostile enemies. There are two paths: using image recognition and using distance sensors. The resulting logic tree was used to determine which solution would be optimal, and can be seen in Figure 3. The optimal solution chosen was to identify anyone who has a weapon using camera image-recognition.

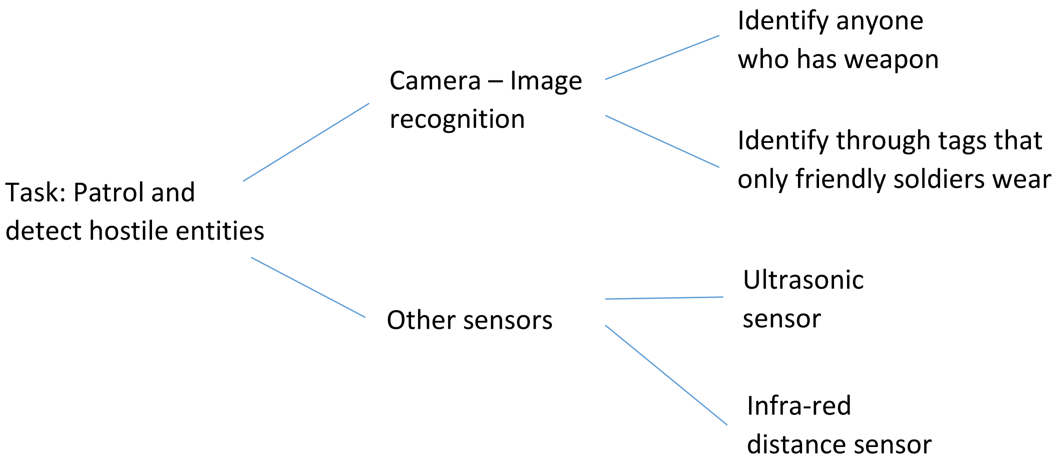


Figure 3 – Logic tree showing the decision-making process behind the robot's choice of sensor

The optimum solution is clearly from the image-recognition side of the tree, as the ultrasonic and infra-red sensors would have trouble identifying as threat. However, there were two choices: identifying through image recognition alone, or through a special tag that only friendly soldiers wear. The final step in defining the system if to integrate the various subsystems of the robot designated by the system boundary definition. This integration is graphically represented in Figure 4. The system has now been defined and any arguments that are explored in the rest of the report now have the required context.

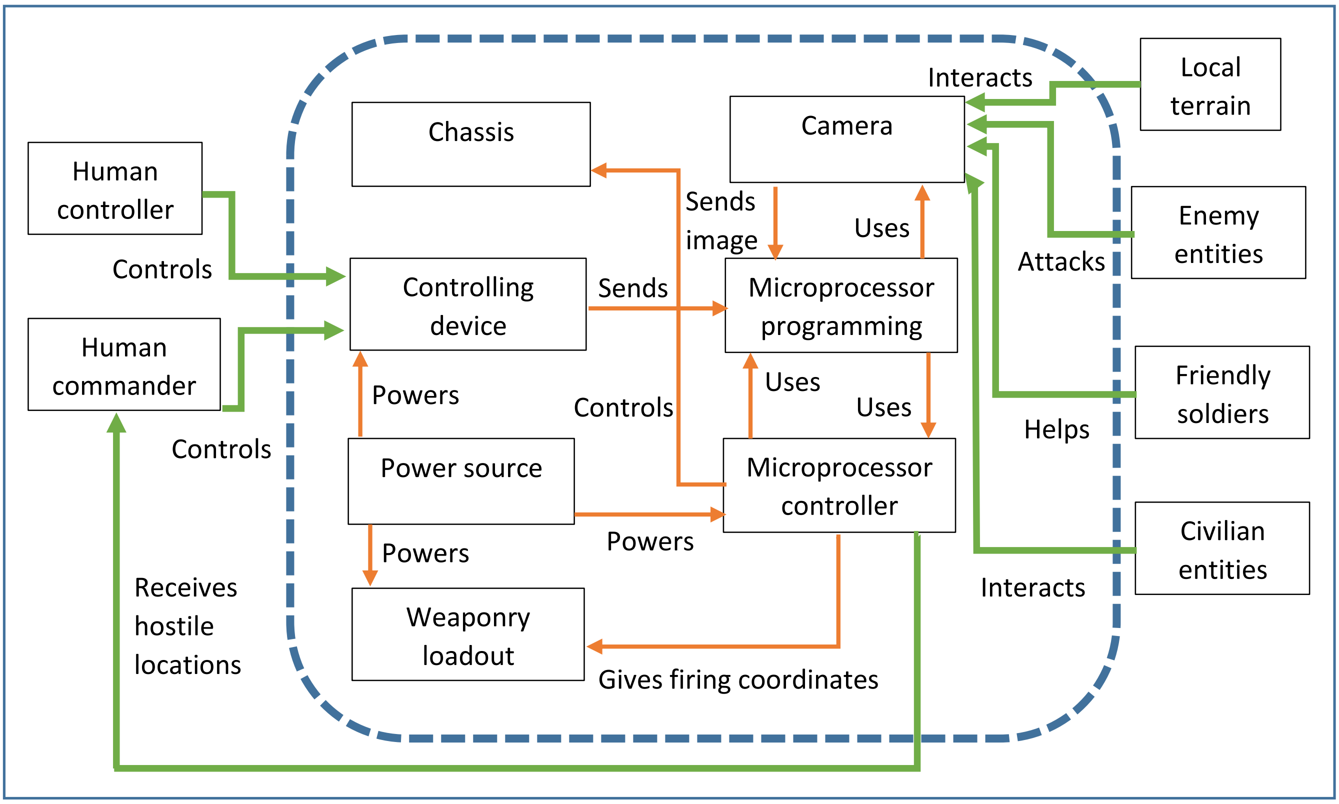


Figure 4 – Subsystem integration graph for military robot showing the system's function

4. Human-interface design

4.1 Ergonomics

One of the most important considerations in the design of this robot is how the human controller will interact with it. This interaction will mainly take place using a controlling device. To increase the ability of a human controller to use the robot, it will be designed so that it can be controlled by a laptop. This laptop will have a user interface that makes it easy to see the status of the robot and its point of view, and the design is shown in Figure 5.

This user interface was created using the Java programming language. This language was used so that all computers, no matter the operating system, could run the program without modifications having to be made. This is especially useful for the military, as it means that system is both durable and reliable, since it can be loaded on any computer that the military has available at the time.

4.2 Anthropometrics

Physical interaction between humans and the robot must also be taken into account. One important part of the robot's interaction with humans is the robot's height. The height of the robot should be taller or near to the height than the average human (~175 cm). However, this would make it far easier to shoot at and spot it when it is out on reconnaissance. As a compromise, the robot will consequently be 60 cm in height. This would both make it a smaller target and also mean that it can still intimidate a human being trying to sneak through the patrol. Finally, the robot must be able to stream video back to the controller's device

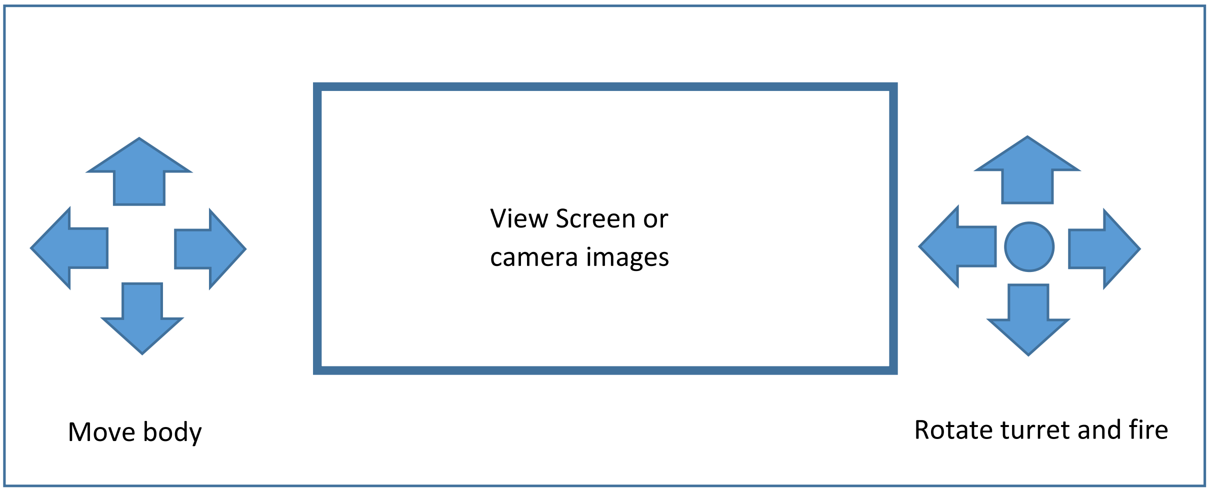


Figure 5 – Probable user interface for usage in military reconnaissance robot

This requires a WiFi connection, as Bluetooth is not powerful enough to stream JPEG images at the required speed. The CPU on the robot will have a video capture with at least 24 FPS, as this is the preferred human image processing speed (Corbett 1987).

Additionally, the interaction between the robot and different types of human beings must be taken into account (Pavlidis & Vincent 1994). There are three types that are relevant to this analysis: friendly soldiers, civilian entities and hostile entities. Friendly soldiers and civilians can be safely ignored, but hostile entities can be dealt with in two ways: (a) shoot at them for intimidation or (b) send a warning back to the base of the robot controller and continue scouting (Kim & Hmam 2009). For this design, option b was chosen as the ideal scenario, based on the surveys conducted in the motivation section of this report, which stated that avoidance of robots becoming directly involved in combat was ideal.

5. Time considerations

Unmanned robots today are often controlled across continents. This means that every second of processing time counts for the robot, and must be minimised as much as possible. The amount of time taken for each action on the robot to complete was measured using a developed prototype robot, as seen in Appendix A, to ensure that it was within the required 1 second to avoid a ‘lag’ of information. This measurement was then used to make a Behaviour over Time (BoT) graph, which is useful for measuring CPU usage over time in the microprocessor. It can be seen from Figure 6 that the CPU usage spikes heavily when an unexpected event occurs, such as in this case a hostile entity encounter.

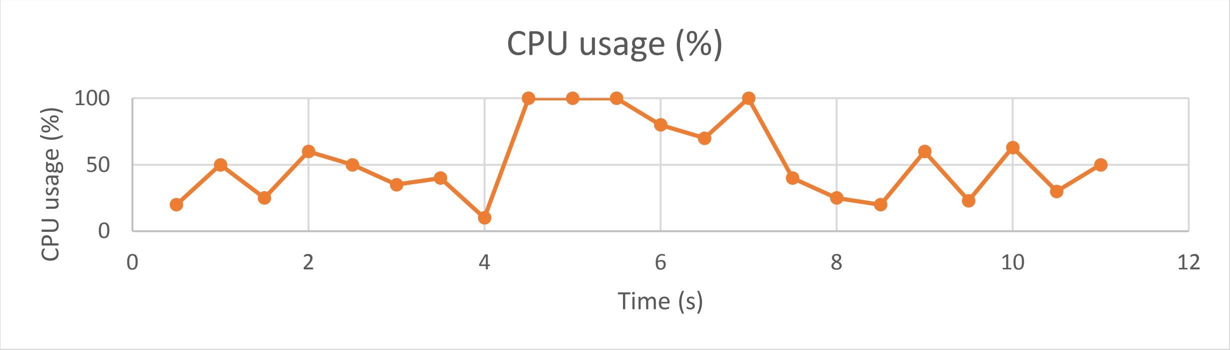
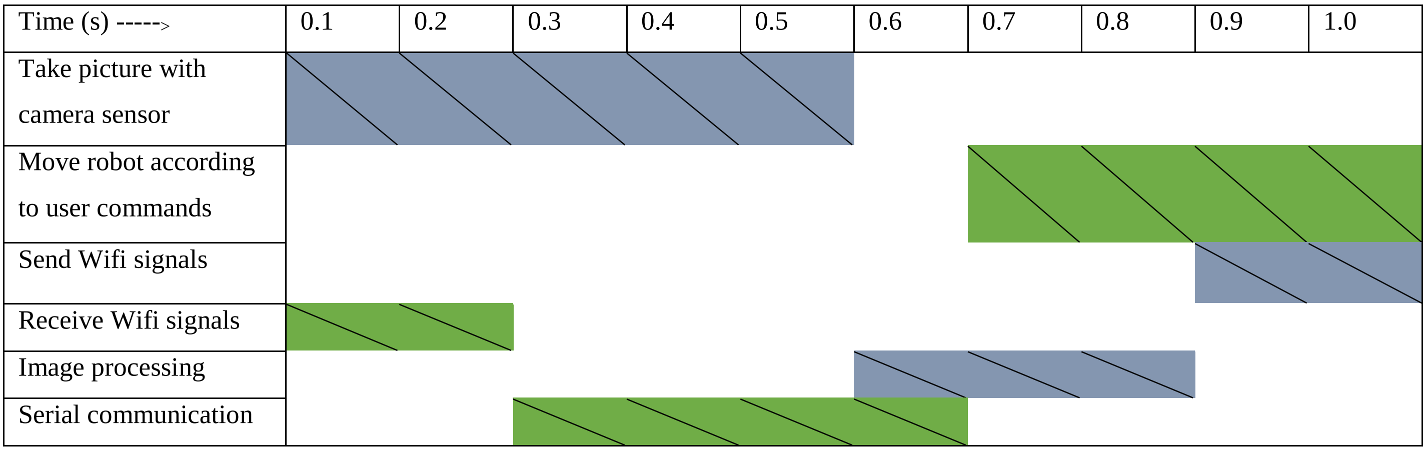


Figure 6 – Behaviour over time for the robot’s CPU when an enemy is encountered at approximately 4.5 seconds

One of the most important features to consider, in terms of time factors, in a user’s experience is the streaming time, or the time it takes for one image to transmit from the robot’s camera sensor to the user input. Queuing theory was an extremely important for this aspect of the robot design, as the WiFi system needs to have two parts: a server, which waits for connections, and a client, which initiates the connection to the server. The data transfer between the two consequently needs to be carefully managed (Gregory 2008). The client is clearly the device that the user handles, and the server would be the microprocessor on the robot. The time measured from each part of the prototype robot’s processes was represented by the Gantt chart in Figure 7, with the time limit on the amount of processing required set at exactly 1 second:



Time (s) ----->	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Take picture with camera sensor	▨	▨	▨	▨	▨					
Move robot according to user commands							🟩	🟩	🟩	🟩
Send Wifi signals									▨	▨
Receive Wifi signals	🟩	🟩								
Image processing						▨	▨	▨		
Serial communication			🟩	🟩	🟩	🟩				

Figure 7 – Gantt chart showing the procedures that a robot will go through every second, green is the movement and grey is image processing portions of procedures

So, from the Gantt chart it was seen that the main tasks that take up the processing power of the CPU are taking a picture with the camera, serial communication between the Beaglebone Black and the Arduino microcontrollers and moving the robot. Unfortunately, none of these can be optimized any further as they are consequences of hardware limitations.

6. Material design concerns

The next step now that the rough design of the robot has been completed is to determine the materials composition of the robot, and the effect these materials could have on the system design, environment and local economy. The materials listed in Table 2 were the ones used for this design. These can be evaluated for embodied energy. Table 2 represents 1526.3 MJ of total embodied energy usage. This is a reasonable amount considering the high-tech and cutting-edge nature of this project.

Table 2 – Material audit for military reconnaissance robot using WattzOn values (WattzOn. 2010)

Part	Materials	Quantity (kg)	Energy involved in manufacture (MJ/kg)	Embodied energy (MJ)
Chassis	Galvanized steel	10	140	1400
Microcontroller (Arduino Mega/Uno)	Gold, silicon, copper etc.	0.01	150	1.5
Microprocessor (Beaglebone Black)	Gold, silicon, copper etc.	0.01	160	1.6
Nerf gun	Plastic	1	90	90
USB Camera	Glass, plastic etc.	0.03	200	6
Cables	Copper and silicon	0.05	100	5
Servos	Plastic and steel	0.1	150	15
Batteries	LiPo (Lithium Polymer)	0.08	89	7.12

As for the microcontroller and microprocessor, the Beaglebone Black was chosen over the Raspberry Pi due to the Beaglebone Black's larger processing power and underlying optimizations, including making the OpenCV library more efficient on the Beaglebone Black than on the Raspberry Pi. The microcontroller section of the system was composed of two Arduinos: one controlling the motors and one controlling the turret servos.

For battery power, LiPo (Lithium-Polymer) batteries were chosen for two reasons: the first is that they are easily rechargeable and the second is that they can release far more power at once than comparable Li-ion (Lithium-ion) batteries. This is important for this high-energy design that uses both heavy-duty servos and motors.

The camera used will be a USB webcam, as this was the cheapest option, costing only $200, in comparison to an expensive robotic webcam which could cost up to several thousand dollars. The chassis of the robot, however, needed to be created out of off-the-shelf components. This problem was solved by using Actobotics, a Meccano-like series, which is composed of steel.

Also, brushless motors were chosen over brushed motors for this robot, due to their ease of use and their simpler setup. Unfortunately, motors large enough to drive a robot this large have stall currents of more than 18 A, which means that if the motor is ever forcibly stopped by running into anything, 18 A of electricity will run through the delicate electronics of the design. This problem was resolved by using specialized MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) motor drivers which were more than capable of handling the larger current. While these were more expensive, the damage that could result from the robot accidently jamming made them well worth the cost. These design decisions mean that the design can easily be scaled up by merely changing the size or shape of the chassis.

6.1 End-of-life issues

In order to take into account the effect of the robot's materials on the environment, the long-term outcome of the robot's materials must be considered, as well as the amount of energy put into the initial construction of the system.

The part of the robot that has the highest potential to malfunction would be the LiPo batteries. These are extremely volatile under the right conditions, such as penetration of the casing or over-charging or lack of charge (McPherson 2003). Consequently, these will be given extra priority in terms of their design safety. For instance, each LiPo battery will have an alarm that sounds when the battery is overcharged or undercharged. One potential issue that could occur when attempting to recycle or safely dispose of the robotic components is that the chassis is not a conventional shape.

Additionally, the Lithium Polymer batteries could also be dangerous to recycle and dispose of. However, in most developed countries the ability to dispose of dangerous materials such as Lithium Polymer batteries is not uncommon (TJinTech 2010). The chassis, however, could be recycled for future productions of the robot as long as the chassis hasn't been catastrophically damaged, due to its galvanized steel composition.

7. Supply-chain for design production

After the exact materials used in the robot have been decided, the next stage of the design process was to determine the supply chain of the materials and components that form the robot design. This process was expected to reveal any possible points of optimization for the design that could make it more efficient to manufacture and less damaging to the environment. The key energy and mass flows of the robot run through the main materials of steel, plastic, silicon, gold, copper and glass. These are manufactured and then turned into components such as microcontrollers, microprocessors, batteries, servos, motors and camera.

After this, the components are combined to form the robot. At the robot's end of life, it is deconstructed and then its remaining parts are either recycled or moved into the garbage tip. In this diagram the main losses would be from the materials coming into the garbage tip, or irrecoverable from battle damage. This can be represented using a Sankey diagram, as seen in Figure 8.

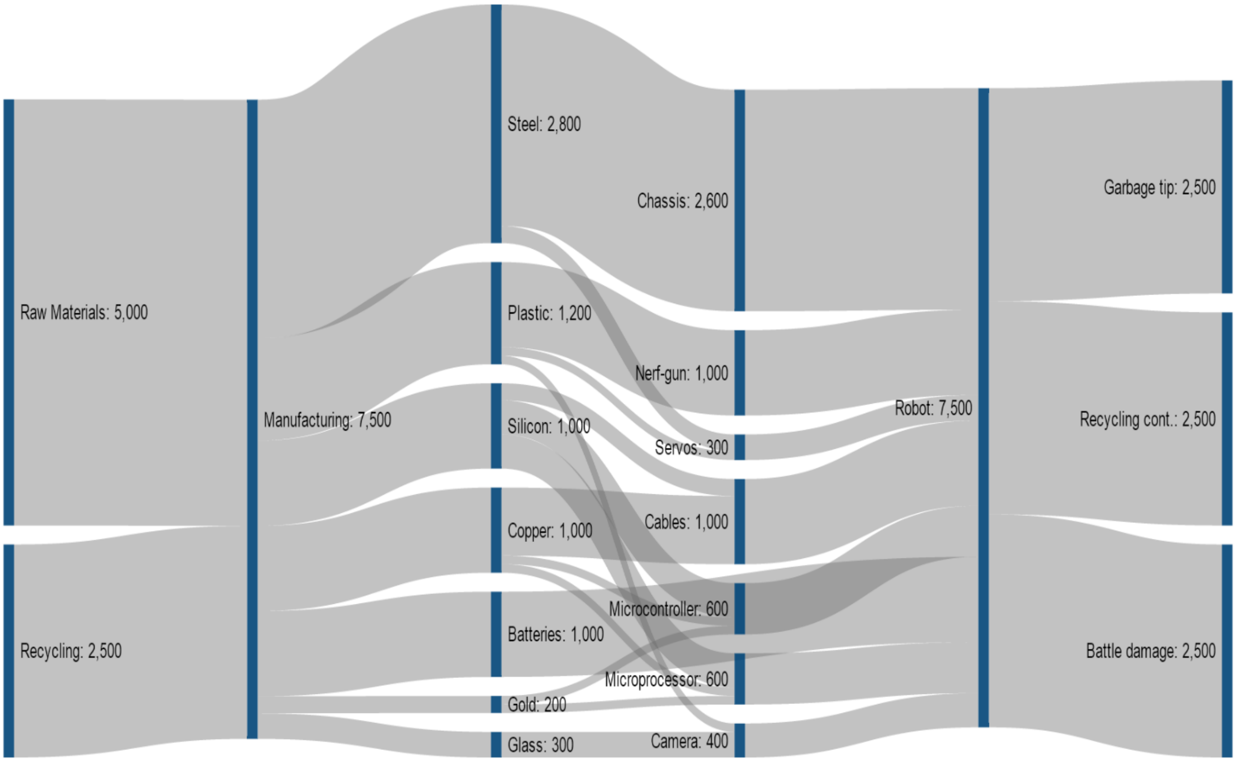


Figure 8 – Sankey diagram of robot's various stages of life (WattzOn, 2010)

So from the Sankey diagram it can be seen that the main method of losses are both the garbage tip and battle damage, i.e. the robot sustaining catastrophic destruction. As the robot is a military one, avoiding battle damage should be considered futile.

Accordingly, one good way to reduce the losses in the output flows would be to increase the number of recyclable parts on the robot, perhaps by choosing a more sustainable chassis. However, another method that could be used to reduce losses could be to increase the durability of the robot to decrease battle damage.

7.1 Identifying critical sub-systems for the control systems programming

The most important sub-systems in this design should be identified so that the control system of the robot can focus on them. This is known as the Pareto principle. There are four variables that have priority in this system: the sensors (the camera), the control system (microcontroller and microprocessor), the battery and the actuators (the motors). Without these the robot would be unable to function effectively. These will be the four key systems used in designing the robot's control system.

8. Dynamics and control of robot

8.1 Defining critical subsystems

With the four important parts of the system now identified, these will can be divided into subsystems so that each part can be conceptualized in Table 3. These defined subsystems can then be used to create the control system.

Table 3 – Table identifying critical subsystems for the control system of the robot

Sensing mechanism	**Actuation mechanism**	**Computation mechanism**
Camera	Motors	Arduino Mega
WiFi receiver/transmitter	Servos	Beaglebone Black
	Nerf-gun	
	Battery	

8.2 Control system design

The main control systems that will be used on this robot will be in the servos used to control the robot arm. The control systems used by the servo should take the error, derivative and integral to create PID (Proportional-Integral-Derivative) control system for smoothly rotating the turret of the nerf-gun towards the desired target (Control Tutorials 2010).

This PID control uses the error generated from the turret's current position to the position it should be in. The Arduino Mega then uses a derivate and integral technique one the positioning data to make sure that the robot stops at the exact point it needs to, rather than moving on past at a continued velocity and having to swing back towards the required point (Kim & Hatem 2009). The first one will be getting the RGB data from the camera and using it to analyse the colour of the surrounding terrain. The other technique will be to create a grayscale image from the taken picture and then use an edge analysis to create depth-perception for the robot (Corke & Sukkarieh 2006).

Importantly, the Wifi system between the Beaglebone and the controlling computer will need to filter the error from the Wifi signals and also filter the encryption key from these signals. This will be achieved by using a comparator-logic control system, which will attempt to remove 'noise' by 'remembering' the last value and adjusting the signal accordingly (Savani & Kapadia 2012). Once the error has been filtered, the decoding process can begin using the Beaglebone Black. The Beaglebone Black can then send the decoded movement instructions to the Arduino Mega for actuation and then chose to transmit camera RGB data and analysis back to the controller.

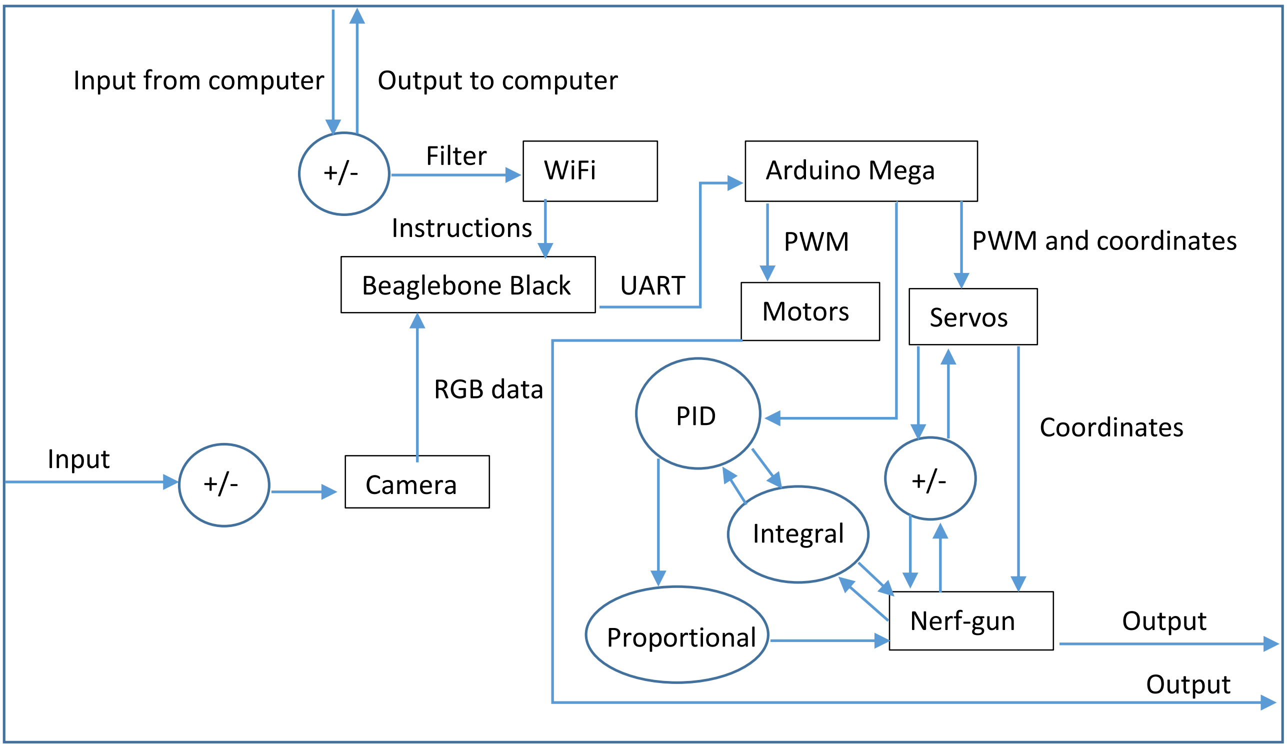


Figure 9 – Control system used by the robot in typical operation

8.2.1 Handling unexpected situations with this control system

However, an unexpected situation could occur such as a hostile entity that is encountered, this is handled by another control system programmed into the Beaglebone Black, as seen in Figure 10.

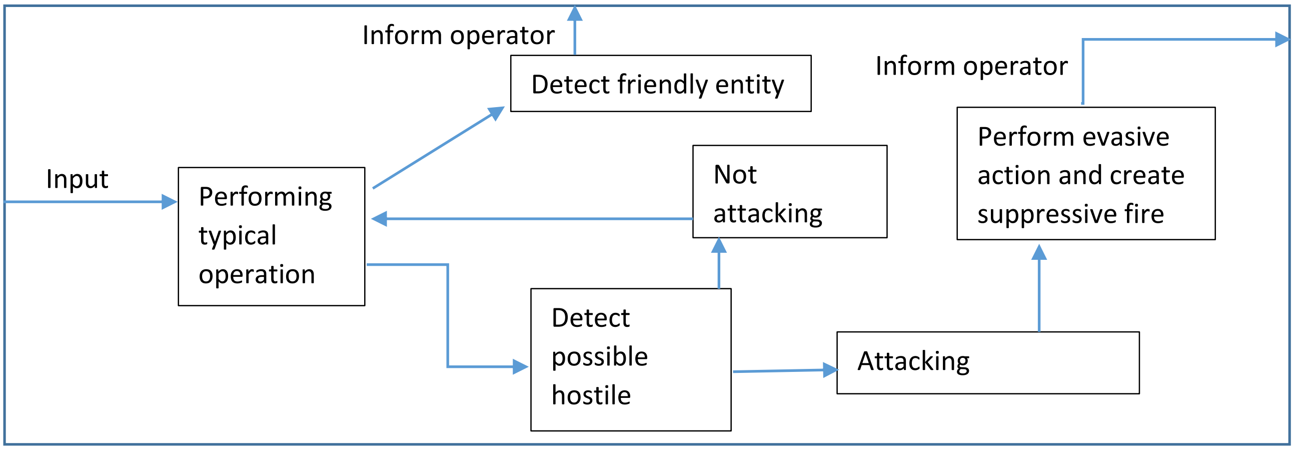


Figure 10 – Control system used in unexpected circumstances

9. Analysis of the total financial price for the design

Now that the design of the robot has been finalized, the most important system factor to examine is the financial cost of the robot. There are two different types of cost to examine: initial and long-term costs. From Table 4 it can be seen that the four most expensive steps are acquisition, refinement, disposal cost and product distribution. The product distribution is open-ended because the cost could increase at any time for many reasons.

One area where the cost could be decreased is definitely in the supply support costs, as these could be decreased by negotiating with the manufacturer of the used components. Additionally, as more units are mass-produced, the cost of building an individual robot will undoubtedly go down as the manufacturing process inevitably becomes more efficient.

Table 4 – Table showing lifecycle costing analysis

Cost Type	**Cost ($)**
Acquisition	2500
Operations	500 p.a.
Software	400 (programmed with Eclipse IDE)
Product distribution	>$5000
Maintenance	$200 p.a.
Test and support equipment cost	$100 p.a.
Training	$250
Technical data cost	$1000
Refinement and disposal cost	$5000
Supply support costs	$1000 for all components

9.1 Pay-back Period

For the purposes of this analysis, the reconnaissance robot will be compared with a standard human soldier on patrolling duty, it can be clearly seen in Figure 11 that a robot quickly pays for itself many times over compared to a human soldier, assuming that the soldier is wounded in the line of duty and has to go on a military pension, or otherwise suffers from PTSD (Post-Traumatic-Stress-Disorder) and has to be removed from active military duty. The point at which the robot soldier becomes more profitable than the human soldier, or payback period, is clearly shown to be roughly 13 months from the plot.

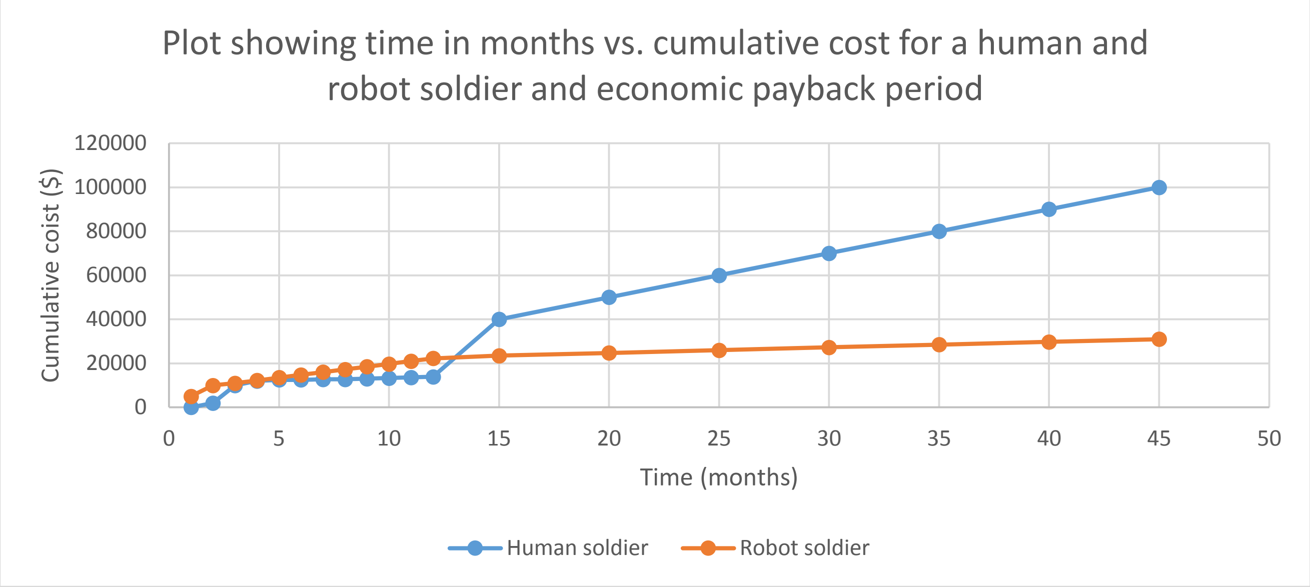


Figure 11 – Plot showing time in months vs. cumulative cost of a human and robot soldier and economic payback period (CNN 2012)

10. Proof-of-concept design

A proof-of-concept design was created using a Beaglebone Black microprocessor for image-recognition, and the OpenCV library in the C++ language. This design was capable of moving along with wheels, and rotating the turret to face a desired location. It can be seen in Appendix A.

11. Recommendations

While this is a successful design, it should be remembered that it is a prototype only. The first recommendation for future designs is that the chassis be reinforced with armour plating to better deal with enemy fire, the second recommendation is that the robot be armed with more powerful weapons than a nerf-gun, such as a machine pistol. To close, the third recommendation is that the robot be upgraded with enhanced software so that it be able to provide aid to friendly nearby soldiers who could be under attack.

12. Conclusion

This design has been successful in achieving all requirements: the robot costs less than $8000 initially, it cost less than $1000 p.a. in maintenance and training costs, it is able to recognise and eliminate enemy threats, it is able to run for more than 8 hours, it is able to communicate with an operator, the vehicle be easily constructible out of off-the-shelf components, the vehicle is extremely easy to repair and the vehicle is scalable to larger sizes if required. Multiple recommendations have also been made that the military can implement on the design if required, and a proof-of-concept robot has been created to show the practicability of the design. Based on these statements, it is clear that this was a successful design.

13. References

Arkin, R 2009, *Governing Lethal Behavior in Autonomous Robots*, 1st edn, Chapman & Hall/CRC Press, 6000 Broken Sound Parkway NW, Suite 300.

Braw, E. 2014. Time to start worrying about ground drones. Available: http://www.newsweek.com/2014/07/18/time-start-worrying-about-ground-drones- 258048.html. Last accessed 7th Aug 2015.

CNN. 2012. The cost of war: Soaring disability payments for veterans. [ONLINE] Available at: http://money.cnn.com/2012/04/27/news/economy/veterans-disability/. [Accessed 30 August 15].

Corbett, Francis J. & Society of Photo-optical Instrumentation Engineers (U.S.). & IEEE Computer Society. & Pattern Recognition Society. 1987, *Image pattern recognition : algorithm implementations, techniques, and technology*: [conference] 12-13 January, 1987, Los Angeles, California / Francis J. Corbett, chair/editor ; sponsored by SPIE--the International Society for Optical Engineering ; cooperating organizations, Computer Society of the IEEE, Pattern Recognition Society SPIE Bellingham, Wash., USA

Galliott, J. 2015, *Military robots: mapping the moral landscape* / by Jai Galliott Ashgate Farnham, Surrey, UK ; Burlington, VT

Gregory, T. U.S. Army Research Laboratory. 2008, *UGS, UGV, and MAV in the 2007 C4ISR OTM experiment* [electronic resource] / Timothy G. Gregory ... [et al.] Army Research Laboratory Adelphi, MD

Hall, Ernest L. 1979, *Computer image processing and recognition / Ernest L. Hall* Academic Press New York International Conference on Field and Service Robotics. & Corke, Peter I. & Sukkarieh, Salah. 2006, *Field and service robotics: results of the 5th international conference / Peter Corke, Salah Sukharieh (eds.)* Springer Berlin http://www.loc.gov/catdir/toc/fy0707/2006923558.html

Kim, Jijoong. & Hmam, Hatem. & Defence Science and Technology Organisation (Australia). Weapons Systems Division. 2009, *Landmark-based navigation of an unmanned ground vehicle (UGV)* [electronic resource] / Jijoong Kim and Hatem Hmam Defence Science and Technology Organisation Edinburgh, S. Aust http://pandora.nla.gov.au/tep/24592

McPherson, J. 2003. Complete Guide to Lithium Polymer Batteries and LiPo Failure Reports. [ONLINE] Available at: http://www.rcgroups.com/forums/showthread.php?t=209187. [Accessed 21 August 15].

Shaker, Steven M. & Wise, Alan R. 1988, *War without men: robots on the future battlefield* / Steven M. Shaker and Alan R. Wise Pergamon-Brassey's Washington

Singer, P 2010, *Wired for War: The robotics revolution and conflict in the 21st century*, 1st edn, Penguin Group, 375 Hudson Street, New York.

Steeb, Randall, John Matsumura, Paul S. Steinberg, Thomas J. Herbert, Phyllis Kantar and Patrick Bogue. *Examining the Army's Future Warrior: Force-on-Force Simulation of Candidate Technologies*. Santa Monica, CA: RAND Corporation, 2004. http://www.rand.org/pubs/monographs/MG140.

TJinTech. 2010. How-To: Safe lipo preparation for disposal. [ONLINE] Available at: http://www.tjinguytech.com/charging-how-tos/lipo-disposal. [Accessed 22 August 15].

Pavlidis, Theodosios. & Vincent, Luc M. & Society of Photo-optical Instrumentation Engineers. & IS & T--the Society for Imaging Science and Technology. & Document Recognition '94. 1994, *Document recognition : 9-10 February 1994, San Jose, California / Luc M. Vincent, Theo Pavlidis, chairs/editors ; sponsored by IS&T--the Society for Imaging Science and Technology, SPIE--the International Society for Optical Engineering* SPIE Bellingham, Wash., USA

WattzOn. 2010. Embodied energy of Electronics and Computers. [ONLINE] Available at: http://legacy.wattzon.com/stuff/items/k7claulbuzuawizd083iq2aofy/ka39mnins6b9t4be22dad2k61y. [Accessed 22 August 15].

World Tribune. 2012. Israeli UGVs on Egypt border called ‘potent psychological weapon’. Available: http://www.worldtribune.com/2012/09/12/israel-deploys-enhancedmore-reliable-ugvs-for-border-operations/. Last accessed 8th Aug 2015.

14. Appendix A – Proof-of-concept robot model