ENGN2225 Systems Engineering and Design

INDIVIDUAL DESIGN PORTFOLIO

Navigational System for Visually Impaired Rowers

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Contents

Abstract

This design portfolio uses a systems engineering approach to develop a navigational aid system for visually impaired rowers. A whole-of-system approach is taken with the primary aim of satisfying the customer's requirements to find the most appropriate design solution. The system techniques utilised allow for a logical design process, and they include system scoping, engineering requirements, functional analysis and subsystem integration. The final concepts, consisting of a sensor and different communication methods with/without GPS, are then evaluated to determine the ideal solution.

Background

Para rowing, previously named 'adaptive rowing', is sweep or sculling rowing for athletes with physical or intellectual disabilities. (World Rowing, 2014) Para rowing challenges barriers to participation in sport, as it accommodates for individuals with learning, physical and sensory impairments. Often normal boat hulls can be fully adapted with stabilizing pontoons, supportive or fixed seats and even gloves to assist with limited hand function. (Howarth, D. 2012) For visually impaired rowers their participation is not necessarily limited by the equipment available but their reliance on a coach or other crew members to guide them when on the water.

285 million people around the world live with a visual impairment, and technology is becoming increasing adept at providing assistance for everyday tasks. (World Health Organisation, 2014) However it is rare for athletes who are visually impaired to be fully independent in their training. Visually impaired rowers rely on having a coach with them throughout whole training sessions to provide them with directions. Coaches are often responsible for a whole squad of athletes, therefore since the coach cannot leave the visually impaired rower unassisted the other crew members often receive limited coaching.

The development of an alternative rowing system using sensory and navigational technologies could allow for visually impaired rowers to become fully independent when rowing in single sculls. It would increase their safety on the water and generally increase the accessibility of the sport.

Solution and Design Communication

The proposed design is a system incorporating a radar sensor device, GPS for navigation and vibrating wristbands for communication with the rower. This system will eliminate the need for directions from the coach and will be attached to the boat as shown in figure 1.

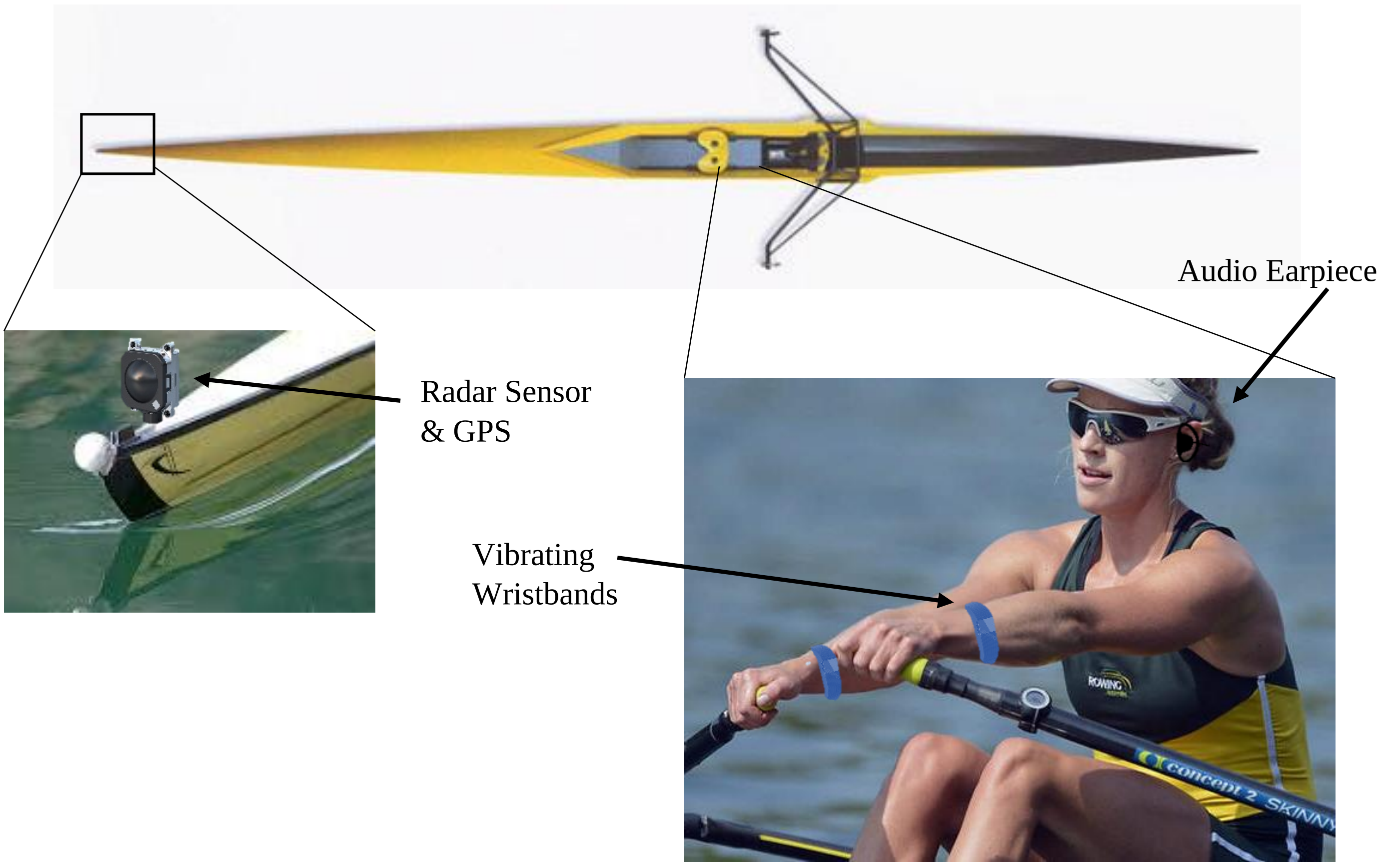


Figure 1: Proposed Design Solution (MAAS, 2014) (SBS, 2013) (Bosche, 2009)

Communicating this design is evidently more complex since the target market will not be able to respond to visual communication. Since this is a very niche market, proposing the design would be best achieved in meeting with various clients and their coaches, and audibly stating the benefits of this design. A brochure could be provided to the coach and the club explaining how the solution would work and the enhanced safety it would provide, as well as further contact details. Upon trial of the design, the device would be used in conjunction with the coach's assistance to ensure the client is confident with interpreting the instructions and comfortable with relying on the device. The device should initially only be trialled with experienced rowers.

System Scoping

Use Case

Establishing what the scope of the problem allows for a more focused design process. The design decisions made are dependent on the use case, as this is the situation that the device will be designed for. The use case for this system can be seen in table 1.

Table 1: Use case for navigational assistance device

Primary Actor	Visually impaired rower
Goal in Context	Provide automated navigational assistance to visually impaired rowers when training
Scope	Rower commencing training to concluding training
Stakeholders	Visually impaired rowers, coach, other club members and the club
Minimum Guarantees	Rower can navigate training course without any collisions
Success Scenario	1. Coach attaches device to boat 2. Rower commences training 3. Rower navigates training safely with minimal verbalised assistance 4. Rower concludes training

Alternative uses

Although the use case is defined above, it is important to consider the potential of such a device in alternative situations before proceeding to analyse the requirements. In essence, all rowers become somewhat accustomed to rowing blind; it's inherent in a sport in which the athlete moves backwards. A crew often relies on the bow member of the boat to check their direction, or a cox to provide steering instructions. In a single however, it is up to the rower to periodically check where they are going and to avoid obstacles.

Providing a visually impaired rower with the ability to row without directional assistance is the primary goal, however this technology could be used in other rowing boats during training to increase safety in the sport. If this device was implemented in coxless boats or used in all singles, it could significantly reduce the number of accidents/collisions and also allow elderly rowers to avoid neck injury by checking their position. A feasibility study was conducted with rowers at the Australian National University Boat Club to determine the potential for alternative uses for this device. The survey found that only 60% thought it was likely to be adopted by other rowers, however 90% thought the technology would likely be a feasible investment for a club.

From this evaluation, it can be concluded that if the design process is followed with a robust solution in mind then it is likely the cost of the design would be funded by the rowers club, relieving the rower of the burden of the cost. Therefore, although cost is initially established as a customer requirement, it will be considered as least important.

Requirements Analysis

Customer Requirements

The primary goal of this design process is to produce a functional design solution that meets the customer requirements. The customer in this case considered to be all visually impaired rowers, and the customer requirements for a directional assistive device were established primarily through a survey conducted on the club members at the ANU boat club. This survey indicated that the device accuracy and providing clear instructions were the fundamental requirements to ensure the safety of the rower. They also indicated that increasing the level of independence as much as possible, not inhibiting boat movement, cost, durability and ease of installation were important.

To allow for decisions to be made throughout the design process, the relative importance of these customer requirements needs to be determined. A pairwise analysis was used, ANNEX A, and the resultant ranking is shown in figure 2. As determined earlier in scoping the problem, cost was frequently traded off for the other requirements and ranked as least important.

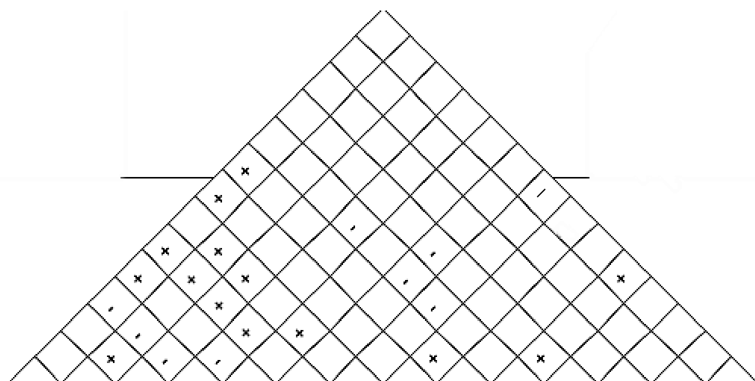
Design Requirements and Technical Performance Measures

The ranked requirements provide an indication of what will be required in the final solution, however they are not useful in measuring how each requirement will be met. To further clarify the problem, the customer requirements need to be translated into design requirements with associated technical performance measures (TPMs). TPMs are based on engineering terminology and use quantitative metrics to evaluate the system. The breakdown of customer requirements into TPMs can be found in ANNEX B, and the determined design requirements, attributes and TPM's are illustrated in the House of Quality in figure 2.

House of Quality

The House of Quality (HOQ) evaluates the interaction between the design requirements and the technical performance measures. The HOQ for this project can be found in figure 2, with the ground floor indicating the relationship strength between the design requirements and TPM's and the roof indicating the relationship between the TPM's. Benchmarks for the TPM's were acquired through research of other collision avoidance technologies and basic analytical calculations using prior knowledge of boat movement.

The strength of the relationships between the design requirements and TPM's are determined to be weak (1), medium (3) or strong (9). The roof allows us to evaluate which TPM's reinforce each other and which will require a trade-off by indicating positive (+) or negative (-) relationships respectively.



Direction		↓	↓	↓	↑	↑	↑	↓	↑	↑	↓	↓	↑	↑	↓
Design Requirement	**Relative Importance**	Communication Time	Error in Distance	Error in Direction	Device Range	Velocity Detection Interval	Field of View	Frequency of human input	Vibrational Intensity	Sound Intensity	Mass	Induced Drag	Waterproof	Yield Strength	Installation Time
Device Accuracy	**1**	3	9	9	9	9	9	1	1	1					
Clear Communication	**2**	9			1	1			9	9					
Required Human Input	**3**	3	1	1	1	1	1	9							
Device Size	**4**										9	9		1	3
Durability	**5**												9	9	
Ease of Installation	**6**										1				9
TPM		ms	m	°θ	m	m/s	°θ	#	Hz	W/m²	kg	N	IP	Pa	s
Performance Benchmarks		<150	<0.1	<1	>40	-10-15	40°	< 5	-	-	<0.5	0	IPX-7	150G	<300

Figure 2: House of Quality

The key outcomes obtained from the HOQ are as follows:

- The accuracy, communication and required human input of the device relate to different TPM's than the device size, durability and ease of installation, which indicates there is no one TPM that can be targeted to meet customer requirements.
- There are trade-offs between the accuracy of the device and the size, as increasing the device accuracy could require a larger device, however according to the pairwise accuracy is more important.
- There are trade-offs between device range and the distance and angle accuracies, as increasing the range of sensors make reduces the short range accuracy. Therefore a balance will need to be met as they are of equal importance.
- There is a trade-off between installation time and frequency of input by the coach, as a less complex device will require less time to install, however the amount of direction required by the coach will be higher.

Functional Analysis

Functional analysis is used to describe the systems requirements in functional terms in order to generate and analyse potential concepts. A method of looking at the functionality of the whole system is to generate a functional flow block diagram (FFBD). A FFBD outlines the functions and sub-functions of a device, which allows for the operational steps in the system to be arranged in a traceable and logical sequence. A FFBD for this system can be seen in figure 3. The main steps involved in this system are outlined chronologically in the top level of the operational flow and two of these top level functions are subsequently decomposed into sub-functional blocks. '&' is used to indicate when all steps are required and 'G' and 'Ḡ' are used to indicate the go and no-go conditions respectively. The maintenance flow indicates the necessary steps if the no-go path is required. (Defence Acquisition University Press, 2001.)

The two top level steps that are explored in greater detail in the second flow level are 'set-up' (REF 1.0) and 'navigate training route' (REF 3.0). The second flow level shows the steps required to complete these top level functions, and further stem into the maintenance steps that may be required if the no-go path is taken.

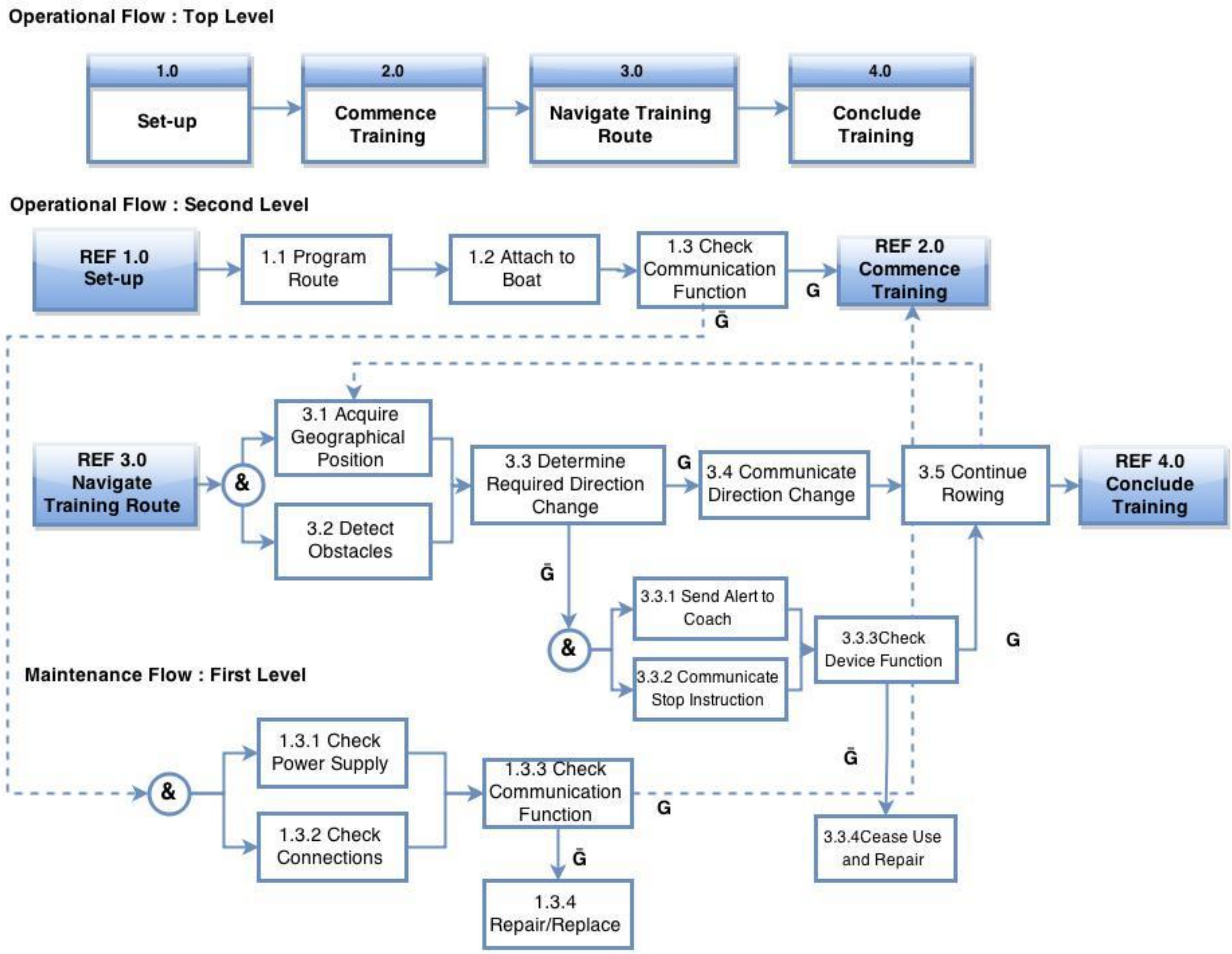


Figure 3: Functional Flow Block Diagram

From the FFBD is can be discerned that the steps involved in the 'set-up' (REF 1.0) and 'navigate training route' (REF 3.0) are essential in ensuring the functioning of the whole system. The 'set-up' relates back to the ease of installation requirement, therefore the 'program route' (1.1) and 'attach to boat' (1.2) sub-functions will be the primary contributing functions for the installation time TPM. To reduce the quantity of this TPM, having a design that is easily attachable to the boat is preferred, and could be achieved by using minimal components and having a wireless system.

The 'determine required direction change' (3.3) subsystem is essential to the 'navigate training route' (REF 3.0) function being completed. Communicating the direction change (3.4) is also an essential sub-function for the training loop (REF 3.1 – 3.5) to be repeated successfully. Determining the required direction change requires a processor to process data from the collision detection system, such as a sensor, and integrating it with the geographical position data if it is obtained autonomously, such as GPS. Geographical position instructions, in regards to the training route, can be provided throughout training by the coach, therefore the data processing that occurs during this sub-function is dependent on how the 'low human input' and 'ease of installation' design requirements are met. The collision avoidance device is an essential function in the system.

Concept Generation

Concept generation is a systematic process of developing ideas and concepts without analysis or preliminary elimination of options. The aim is to refine the concepts purely through analysing how they affect the customer needs, after considering the full space of alternatives. Concept generation was completed for this report and the concepts that were determined to merit further consideration were classified and put into a classification tree which is shown in figure 4.

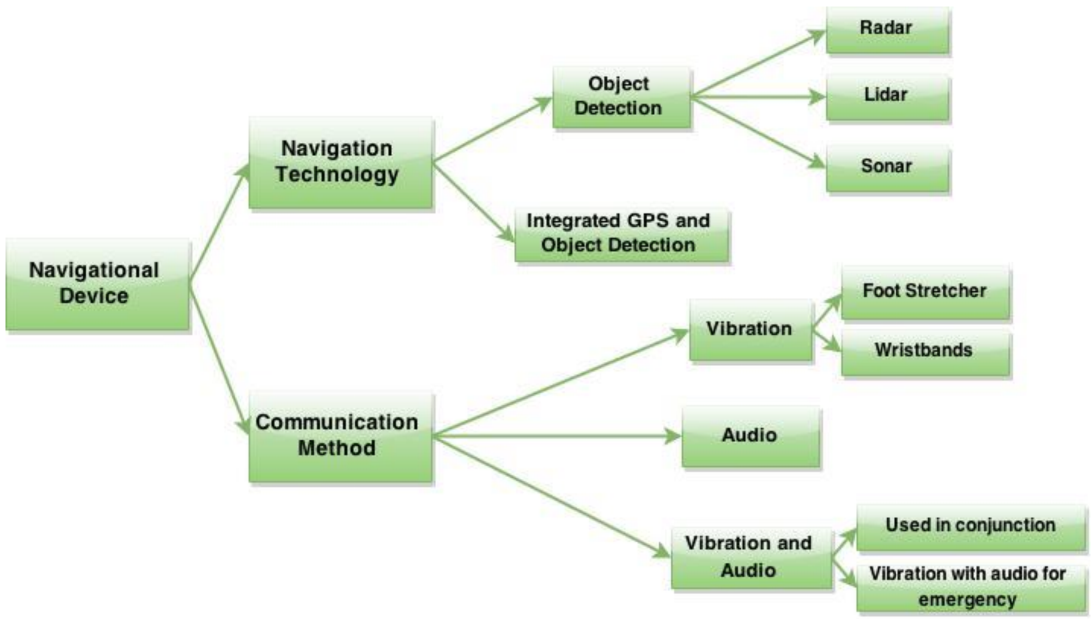


Figure 4: Concept Generation Tree

The concepts generated were classified into two main categories: 'navigation technology' and 'communication method'. Both of these categories had various concepts associated with them that each meet different design requirements. This holistic approach allowed for various design solutions to be considered, and the concept which most satisfies the predetermined requirements and benchmarks TPM's will be determined later in the evaluation matrix.

The concept generation process has also given an indication of the subsystems that make up this design, as several concepts had underlying interrelations in regards to the components they would consist of (Ulrich, K.T., and S.D. Eppinger, 1995).

Subsystem Integration

Subsystem integration reveals the system architecture by analysing the interfaces between subsystems and their role in meeting the customer requirements. Analysing the overall inputs and outputs helps to simplify the design process and allocating functions to the subsystems allows the modularity of the system to be recognised. A functional block diagram (FBD) will summarise the subsystem interactions, such that the effect of design changes can be traced in terms of the resultant output.

Firstly it is important to define the system boundaries to establish what elements will be included in the FBD. A system boundary chart is shown in table 2, with the included column defining what can be controlled within the system, the excluded column defining factors that will be considered important but cannot be changed and the outside column indicates what factors will not be taken into account in the system design as they do not directly affect the system. The severity of the visual impairment was put outside the scope because this system will provide standard directional assistance, regardless of impairment severity. The weather and water conditions will also not be considered inside the system design.

Table 2: System Boundary Definition

Included	Excluded	Outside
Attachment	Boat	Severity of visual impairment
Size	Objects	Weather
Cost	Coach	Water conditions
Accuracy	User	Time of day for use
Communication		
Appearance		
Resistance to water exposure		

The system was segregated into five distinct subsystems. Before analysing the interactions, the subsystems need to be defined. The first is the object detection subsystem, which detects any physical object on the surface of/partially submerged in the water, acquiring its distance and relative velocity. The detection is then converted into an appropriate signal and transmitted to the processing subsystem for calculation. The route navigation subsystem provides data in relation to position on the water and the programmed route, which is also transmitted to the processing subsystem for calculation. The processing subsystem takes the input data from both the object detection and route navigation subsystems, processes the data using a program to determine the direction and required force adjustment. The communication subsystem receives the processed data from the processor in the form of a signal indicating the direction and force change required, and outputs this information to the rower. The power subsystem supplies the required power to the other subsystems. The interactions between these subsystems and the inputs and outputs of the system are shown in the FBD in figure 5.

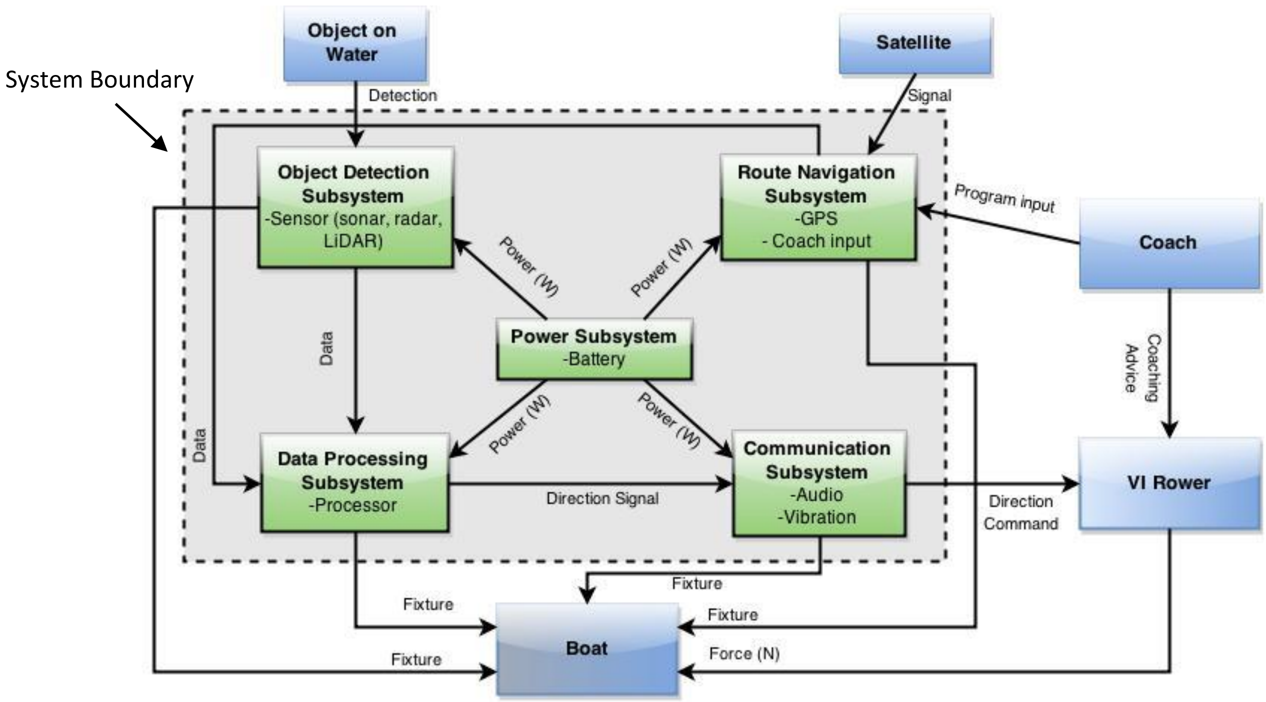


Figure 5: Functional Block Diagram

This FBD shows the basic subsystem interactions for the general conceptual system design. The flow of interaction shows the reliance of the communication output on data receiving and processing, and therefore the integral role of the object detection and geographical positioning inputs. Optimising the reception of these inputs by increasing the accuracy of the reception devices would increase the reliability of the communication output.

Data processing is evidently the crucial link between the navigation data and communication, and will therefore require sophisticated data processing software. This level of sophistication is reliant on the level of required input from the coach, and will affect the direction commands provided to the rower by the system.

The sensor range of the object detection subsystem will directly impact the processing time of the system, therefore having a high sensor range will be necessary to reduce the processing time TPM.

It is important to also note from the FBD that the user receives input from the communication system as well as the input from the coach, therefore the communication system will need to be designed to avoid interference between these two inputs. Therefore the audio concept determined previously as a method of communication would either have to be fitted in only one ear, or used in conjunction with the vibration concept in the case of emergencies. The direction instructions will need to be clear enough that the direction command interaction correctly transfers to the force applied by the rower to the boat.

An attributes cascade was used to relate the customer requirements to the defined subsystems. The cascade begins with the related design requirement as the ‘primary attribute’, branches into the more detailed ‘secondary attributes’, which are methods used to achieve the primary attribute. ‘Tertiary attributes’ are methods to achieve the secondary attributes. The attributes cascade for accuracy, as the most important customer requirement, can be found in ANNEX C.

Validation and Evaluation

Validation

Design validation determines the extent to which the system design aligns with the customer requirements using different testing methods for the various system attributes. The test procedures outlined here are determined for the secondary attributes associated with the device accuracy requirement, as accuracy is the highest ranked customer requirement. However testing of other attributes would be necessary before evaluating the various concepts.

The testing procedures that can be used to determine the most accurate and reliable object detection sensor were derived from a paper by Birdsong, C. et al on sensors for a pre-crash detection system in a car. The tests are described as follows:

Table 3: Validation Testing (Birdsong, C. et al. 2005)

Attribute/s	**Procedure**
Field of View Range and Minimum detectable object size	*Proof of Concept Testing* *Pass Criteria: Scope angle > 120°, minimum object size <0.4m* *Procedure:* 1. Fix sensor in position 2. Place a target at specific positions at pre-identified distance and angle from the centreline of the sensor. 3. Sensor output is compared to target distance using a tape measure and protractor from the sensors centre.

	3. Repeat for a range of angles and record which objects were detected, then repeat experiment with next object size 5. Determine highest angular range in which objects were consistently detected (above 90%) and the minimum object size detected. Repeat for each sensor type.
Accuracy	*Proof of Concept Testing* *Pass Criteria: error <±10%* *Procedure:* 1. Fix sensor in position 2. Place targets at varying distances and angles, compare sensor output with actual distances to determine the deviation Note: This accuracy test only includes a standard sized object, therefore could be repeated with objects of various shapes and sizes
Distance Range	*Analytical* *Pass Criteria: range > 40m* *Procedure:* 1. Research ranges supplied by the manufacturer
Reliability of Direction Change	*Analytical* *Pass Criteria: Model confirms all collisions are avoided after a series of simulations* *Procedure:* 1. Develop a computer simulation of the boat movement using the specifications of various sensor types attached and implement the program that calculates the required direction change 2. Evaluate how many collisions are avoided *Prototype* *Pass Criteria: The rower can row a set distance without risk of collision* *Procedure:* 1. Set up a course with a series of soft buoys of various sizes placed on it 2. With a rower blindfolded, row through the course and record the number of buoys hit 3. Repeat multiple times, then replicate with each sensor type Note: This test is inaccurate in not considering moving objects, and therefore would need to be repeated with objects moving at set velocities

The above tests show that the attributes surrounding accuracy are predominately quantitative, providing an accurate means of determining which object detection sensor is most suitable.

To validate which communication concept best aligns with the customer requirements, it needs to be considered that the most ideal concept will be subjective between users. This is predominately because rowing is a sensory sport, and choosing which method least impedes other senses for each individual is important. Therefore a group of rowers were surveyed and asked which method they think would be most effective for a rower, and two thirds responded with a combination of audio and vibration. The comments provided said that this option was best so as to not overload any one sense, to ensure the directions were understood and to make sure the rower could still receive input from the coach. Therefore the refined concepts to be considered are whether the vibration should be implemented in the foot stretcher or in the form of wristbands.

The optimal audio and vibrational intensities, as per the design attributes, would still need to be tested. This could be done by conducting a survey in which people were subject to signals of various vibrational and audio frequencies and had to determine between ‘high’ and ‘low’. This would assist in determining what frequency range gap provided the easiest differentiation.

Evaluation

Evaluation allows for the comparison of various design solutions, to determine which best meet the customer requirements. This is done quantitatively using weighted comparisons based on the ranked importance evaluated previously in the pairwise analysis. The first evaluation matrix compares sensor types for the object detection system by determining how they comply with design attributes associated with accuracy. Since accuracy is the most important customer requirement, compliance with these attributes is mandatory. Therefore the various sensors are evaluated on a pass/fail criteria, and if fail are eliminated as design possibilities.

Table 4: Mandatory evaluation matrix for sensor accuracy

Design Attribute for Accuracy	**Radar**	**LiDAR**	**Sonar**
Field of View	Pass	Pass	Pass
Distance Accuracy	Pass	Pass	Pass
Angle Accuracy	Pass	Pass	Pass
Distance Range	Pass	Pass	Fail
Relative Velocity Detection	Pass	Fail	Fail

The results of this mandatory evaluation matrix, table 4, shows that the only sensor type that passed was the radar sensor, since its distance range can be extended and shortened depending on the type chosen and it has the ability to detect the velocity of oncoming objects. LiDAR sensors lack the ability to provide dynamic information about detected objects, and sonar sensors can only provide short range detection, e.g. within 6m. (Gohring, D, 2012) (Whitwam, R. 2014) Therefore the resultant potential solutions are as follows:

1. Radar sensor, audio and vibrating foot stretcher for communication, integrated with GPS

2. Radar sensor, audio and vibrating wristbands for communication, integrated with GPS
3. Radar sensor, audio and vibrating foot stretcher for communication, no GPS
4. Radar sensor, audio and vibrating wristbands for communication, no GPS

The weighted evaluation matrix for these solutions is shown in table 5.

Table 5: Weighted Evaluation

			Solution 1		Solution 2		Solution 3		Solution 4	
Customer Requirements	**Rank**	**Weighting**	**Compliance**	**Weighted Value**	**Compliance**	**Weighted Value**	**Compliance**	**Weighted Value**	**Compliance**	**Weighted Value**
Device Accuracy	1	6	5	30	5	30	5	30	5	30
Clear Communication	2	5	3	15	5	25	3	15	5	25
Increases Independence	3	4	5	20	5	20	1	4	3	4
Uninhibited Boat Movement	4	3	3	9	3	9	3	9	3	9
Durable	5	2	3	6	3	6	3	6	3	6
Easy to Install and Detachable	6	1	1	1	3	3	1	1	3	3
				80		**93**		**65**		**77**

From the evaluation matrix the most suitable design is determined to be solution 2, the radar sensor integrated with GPS, using vibrating wristbands and audio for communication. The two designs using the wristbands were highest ranked because installation of vibration pads in the foot stretcher would be more difficult to install/detach, and the signal would not be as clear due to the force that needs to be applied to the foot stretcher during the stroke. The GPS is necessary to increase the independence of the rower, which will enable the rower to train safely with minimal amount of assistance from others.

Conclusion

This design process began with the fundamentals of scoping the problem and evaluating the design requirements, so that in comparing various concepts the most suitable option for the customer was able to be determined. It was found that a design with vibrating wristbands, a radar sensor system and GPS capabilities was the optimum design solution for visually impaired rowers.

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ANNEX A

Pairwise Analysis

	Ease of Installation	Durability	Uninhibited boat movement	Communication	Accuracy	Level of Independence	Cost	Sum	Rank
Ease of Installation		0	0	0	0	0	1	1	6
Durability	1		0	0	0	0	1	2	5
Uninhibited boat movement	1	1		0	0	0	1	3	4
Communication	1	1	1		0	1	1	5	2
Accuracy	1	1	1	1		1	1	6	1
Level of independence	1	1	1	0	0		1	4	3
Cost	0	0	0	0	0	0		0	7

ANNEX B

Customer Requirement Breakdown

Customer Requirement	Design Requirement	Design Attributes	Metric (TPM)	Direction	Related Subsystem
System detects and avoids objects	Device accuracy	Error in distance	distance (m)	↓	Object Detection
		Distance range	distance (m)	↑	
		Error in direction	angle (θ)	↓	
		Velocity interval	range (m/s)	↑	
		Field of view	angle (θ)	↑	
Increases independence	Low human input	Frequency of voiced instructions required	number (#)	↓	Route Navigation
Instructions easy to interpret	Clear communication to user	Vibrational intensity	frequency (Hz)	↑	Communication
		Sound intensity	Intensity (W/m^2)	↑	
		Communication time	time (ms)	↓	
Boat movement is uninhibited	Device Size	Mass	mass (kg)	↓	All
		Induced drag	force (N)	↓	
Durable	Durability	Waterproof	IP rating	↑	All
		Yield Strength	stress (Pa)	↑	
Easy to install and detachable	Ease of installation	Installation time	time (s)	↓	All

ANNEX C

Attributes Cascade

Primary Attribute	Secondary Attributes	Tertiary Attributes	Related Subsystem
Accuracy	Detection Accuracy	Shorter range with more accurate frequency	Object Detection
		Higher sensitivity to object position	
	Range of Device	Increased field of view	Object Detection
		Increase distance detection range	
	Detecting Relative Velocities	Narrower beam width	Object Detection
		Reduced angular resolution	
	Integrate with geographical position data	Obtain data from GPS	Route Navigation
	Efficient processing	Efficient data transfer to processor	Data processing subsystem