ENGN2225 Individual Design Portfolio

Wired Bike Computer System for Australian Cyclists

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Abstract

This research focuses on bike computer technology in the commercial market, and uses the systems engineering design approach to seek to improve computer's the maintenance aspect. The design processes include engineering requirements, system definition, subsystems integration, system attributes, verification, evaluation and design communication. Upon the completion of these steps, it is found that a solar-powered bike computer meets the cyclists' requirements better than a typical replaceable battery bike computer.

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1.0 Background Information

1.2 Bike Computer and the Low Usage by Australian Cyclists

Figure 1 - A typical bike computer

A bike computer (also known as cycle computer) is a small electronic gadget that is capable of displaying instantaneous speed, average speed, total distance, trip distance as well as time (Figure 1).

A survey is conducted that aims to understand the need by Autralian cyclists and find out possible suggestions on how the current bike computers may be improved. In brief, the survey identifies that while 78.9% of cyclists have expressed that they want to know the speed and distance when cycling, 10.5% actually own cycle computers. When asked how a typical model may be improved, 31.5% of the cyclists that don't own bike computers have connected to power-related aspects, such as external recharge feature, easy battery replacement and solar-powered etc.

The results from the survey is self-evident that, while bike computer usage in Australia is very low, there is great market potential that has not been explored. Therefore, this design portfolio focuses on a typical wired bike computer, and improves the maintenance aspect by applying system engineering theory and a whole-of-system design approach.

1.3 Solution and Design Communication

Figure 2 - A solar-powered model in US market (Vetta. 2014)

While many solar-powered bike computers are available in many other countries (figure2), very few model has reached the Australian cycling market. From the systems design process, we found that a solar-powered design can best meet the design criterion of easy maintenance. An example of a US model is shown below. To convey this design to the Australian public, it is necessary to employ effective mass communication methods, such as newspaper, magazine, in-stored promo and internet communication. Targeting individuals or small groups of people will be inefficient and costly. TV advertisement is likely to be impractical due to huge cost. On the other hand, relatively cheap options like newspaper and magazines can be used that communicate the design to the public, especially to Australian cycling community. The communication should include a sound justification on why a solar-powered bike computer requires much less maintenance effort, and why it is better than a traditional replaceable battery bike computer. Good photography of a solar powered model is also needed to appeal the public, along with some other features to appeal more specific group, like the eco-friendly feature that may appeal environmentalists.

2.0 Engineering Requirements

The first stage, engineering requirements, is a crucial and defining process in any engineering design process. This requires us to understand precisely what the customer requirements are, how the requirements are prioritised, and how they are converted into measureable parameters (Blanchard, 2011). For bike computer, the customer requirements are understood by a survey, which is given to people who own a cycling computer as well as to those who do not.

2.1 Requirements in the Survey

2.1.1 User-friendly: Has a good user interface and is easy to read.

2.1.2 Reliable: Gives correct reading with very small error and not subjected to frequent failure.

2.1.3 Robustness: water proof and not breaking upon collision.

2.1.4 Easily Maintainable: The survey discovered that lots of people are concerned with the power supply, which should require less effort and less cost to maintain.

2.1.5 Flexible: Night use, removable (prevent theft), different modes of operation

2.1.6 Easily installable: A simple set up process for first use

2.1.7 Low Cost: A typical bike computer on market costs as low as $AU15.

2.1 Pairwise Analysis

We can use pairwise analysis (Table 1) to prioritise the customer requirements, which allows us to quantify the relative importance in the context of the bike computer in Australia.

	User friendliness	Reliability	Robustness	Easy Maintenance	Flexibility	Easy Installation	Low cost	Sum	Rank
User friendliness	-	0	1	0	1	1	1	5	3
Reliability	1	-	1	1	1	1	1	6	1
Robustness	0	0	-	0	1	1	1	3	4
Easy Maintenance	1	0	1	-	1	1	1	5	2
Flexibility	0	0	0	0	-	1	0	1	6
Easy Installation	0	0	0	0	0	-	0	0	7
Low cost	0	0	0	0	1	1	-	2	5

Table 1 - Pairwise analysis table

Importance Ranking	Customer Requirement
1	Reliability
2	Maintenance
3	User friendliness
4	Robustness

Table 2 - Importance ranking of the top four customer requirements

2.2 Technical Performance Measure

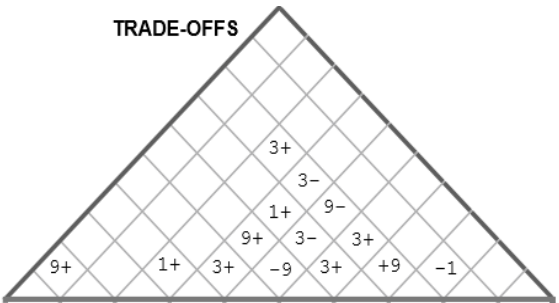
According to (Blanchard, 2011), the Technical Performance Measure (TPM) are "quantitative values" describing an engineering system. These are the parameters that assess if the system meets the customer requirements. For the purpose of this design portfolio, the four top customer requirements (Table 2) will be focused. The TPM (Table 3) will serve an important role in identifying the aspects that can be improved for a typical bike computer.

Rank	Customer Requirement	ID	Design Requirement/Attribute	Engineering Characteristic	Metric(TPM)
1	Reliability	DR01-01	Gives correct readings	Error in speed	m/s (speed)
				Error in distance	m (length)
		DR01-01	Minimal failure rate	Failure frequency	% (percentage)
2	Maintenance	DR02-01	Effort & cost per maintenance cycle	Time taken to recharge/replace batteries	min (time)
				Cost of power	AU$ (dollars)
		DR02-02	Long maintenance cycle	Battery life	days (time)
3	User friendliness	DR03-01	Clear display	Max. distance to read	m (distance)
				Display light intensity	lumen (luminosity)
				Angle of display inclination	degrees (angle)
		DR03-02	Easy User input	Num. of buttons	num.
4	Robustness	DR04-01	Rainproof	Max rain intensity without failing	mm/h (rain intensity
		DR04-02	Structural strength	Max allowable stress	Pa (stress)

Table 3 - The Technical Performance Measures for bike computer

2.3 The House of Quality

LEGEND
1: Weak relationship
3: Medium relationship
9: Strong relationship
+/-: positive/negative
: increase/decrease (ECs)



ID	DESIGN REQUIREMENTS (AKA Customer Attributes)	RELATIVE IMPORTANCE	- error in speed	- error in distance	- time to recharge/replace batteryies	- cost of power supply	+ battery life	- net power consumption	+ maximum reading distance	- display light intensity	• angle of display	
DR01-01	Gives correct readings	1	9	9				1				
DR02-01	Low effort & cost per maintenance cycle	3			9	9	3					
DR02-02	Long maintenance cycle	4			1	3	9	9	1	3		
DR03-01	Clear display	2					3		9	9	3	
		METRIC/TPM	m/s	m	s	AU$	days	watt	m	lumen	ˇ	

Table 4 - The House of Quality

The TPM constructed in 2.2 can subsequently be used to construct the House of Quality (Table 4), which highlights the interrelationships and trade-offs in the bike computer regarding to the design criteria and engineering characteristics (Hauser & Clausing, 1988).

The commercially available bike computers have already achieved good accuracy and clear display (see Verification section). However, it is identified in this section that people want bike computers to be maintained more easily. There are several possible contributing factors. Firstly, wired bike computer is powered by batteries, and replacing them is a difficult thing to do. Secondly, opening the computer to replace batteries might cause accidental damage. Secondly, the cost of battery is around AU$8-10, which is relatively expensive compare to the cost of the computer itself (Shahriyar, 2012). Current wired computers use replaceable batteries as the power supply. Hence, in the next section we analyse alternative power supply methods with the aim of making the maintenance process easier and faster.

3.0 Defining Bike Computer System Functions

In defining the system functions for a cycle computer, we transform the functional requirements (from engineering requirements) to sequential functional processes that must occur (NASA, 2006). It is useful in understanding the functional mechanism of a bike computer.

3.1 Functional Analysis on the Current Bike Computer

The primary technique for functional analysis is the functional flow-block diagram (FFBD), which illustrates the individual functions in a system as well as the sequential flow from one function to another so as to ultimately fulfil the design requirements (Department of Defense, 2001). The FFBD (Figure 3) for a wired bike computer focuses on the maintenance level.

From the FFBD, we identified the maintenance level when the bike computer is found not displaying good output. This begins with a visual inspection for any physical damage. Then we might check one of more of the following three things – connection, setting or power. If the system is running but not displays appropriate output, then it is likely due to either connection failure or improper setting. However, if the system is not running at all, then we should check the power supply.

3.2 Concept Generation

The aspect that we can improve is the power supply (maintenance) of a bike computer. To aid the design process, we carry out a concept generation process that can be illustrated in the Figure 4. A vigorous concept generation on the maintenance effectively avoids the situation of stumbling across a superior idea later.

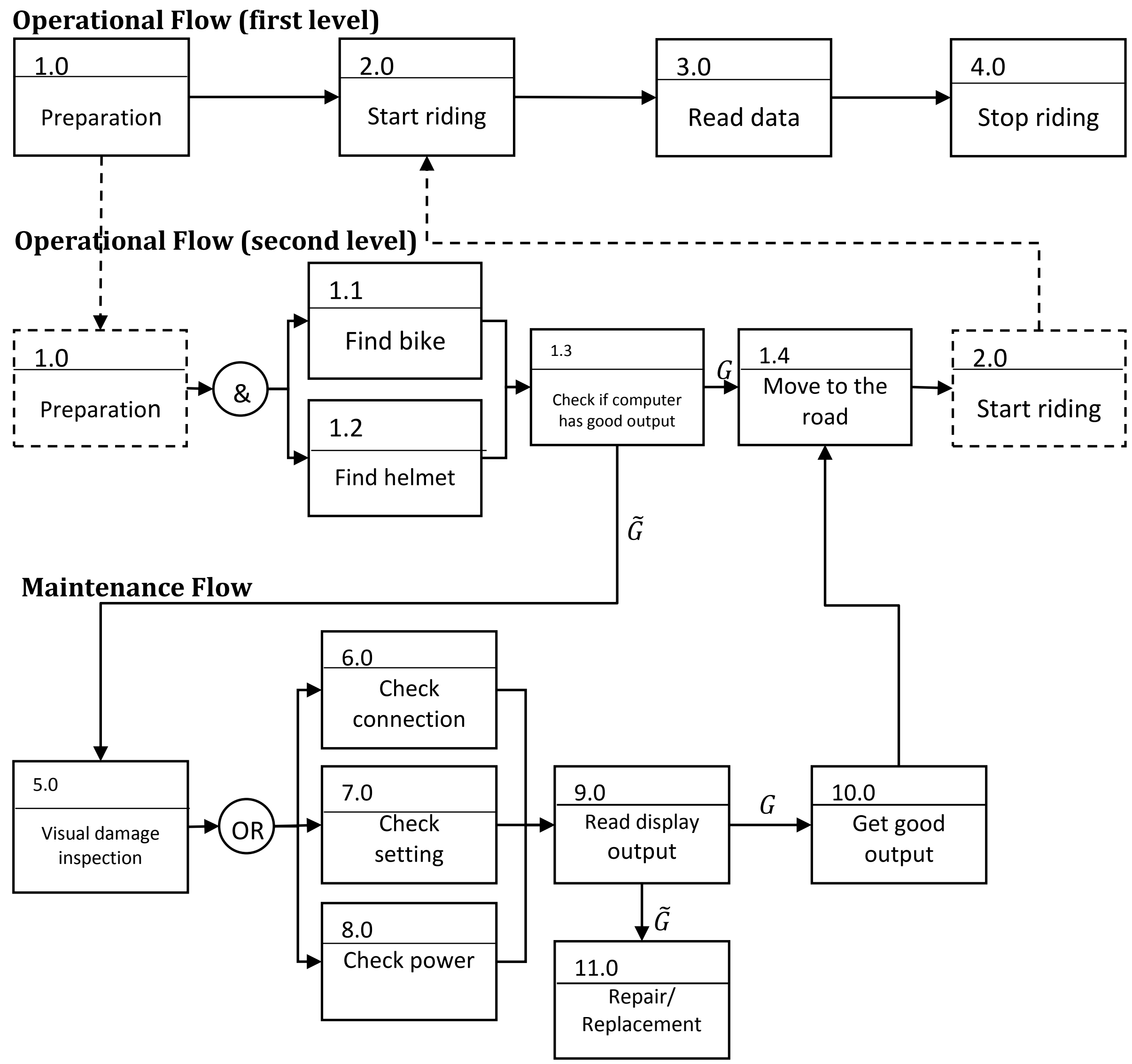


Figure 3 – FFBD for the current wired bike computer

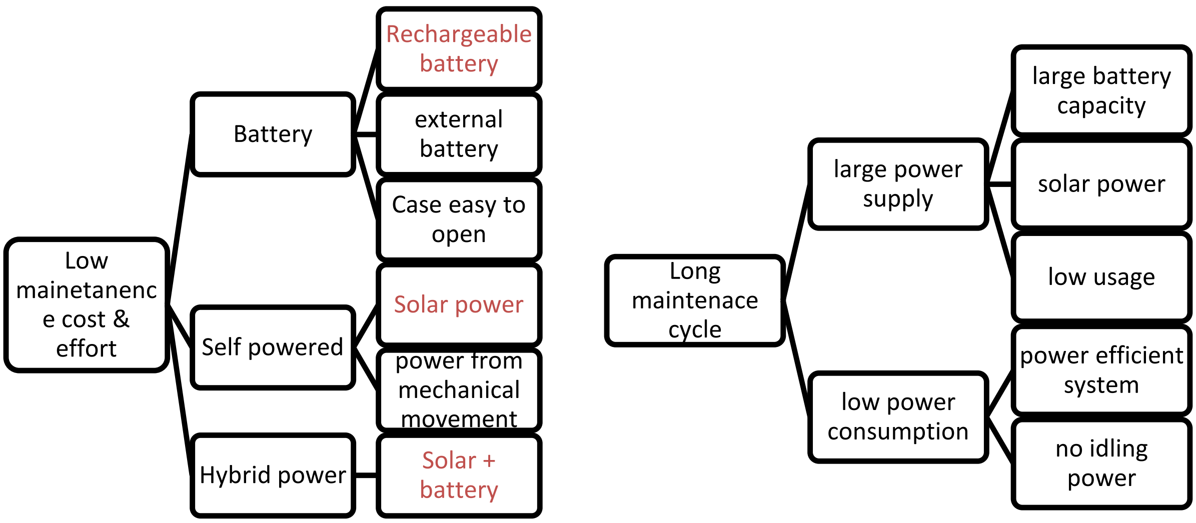


Figure 4 - Concept generation

3.3 FFBD for Rechargeable Battery, Solar Power and Hybrid Power

From the concept generation, three good options for power supply are rechargeable battery, solar power and a hybrid power. By constructing the second maintenance level for each method, we can see that the solar power option requires the least amount of maintenance effort and cost.

3.3.1 Solar power FFBD (maintenance flow for checking power)

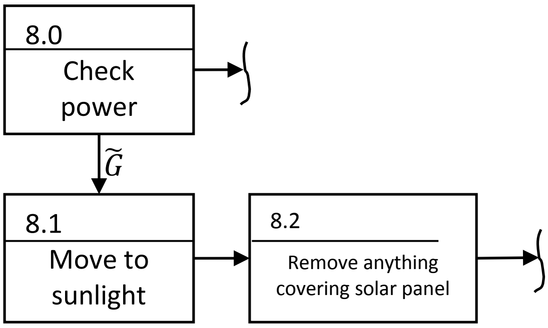


Figure 5 - FFBD for solar power option

3.3.2 Rechargeable battery FFBD (maintenance flow for checking power)

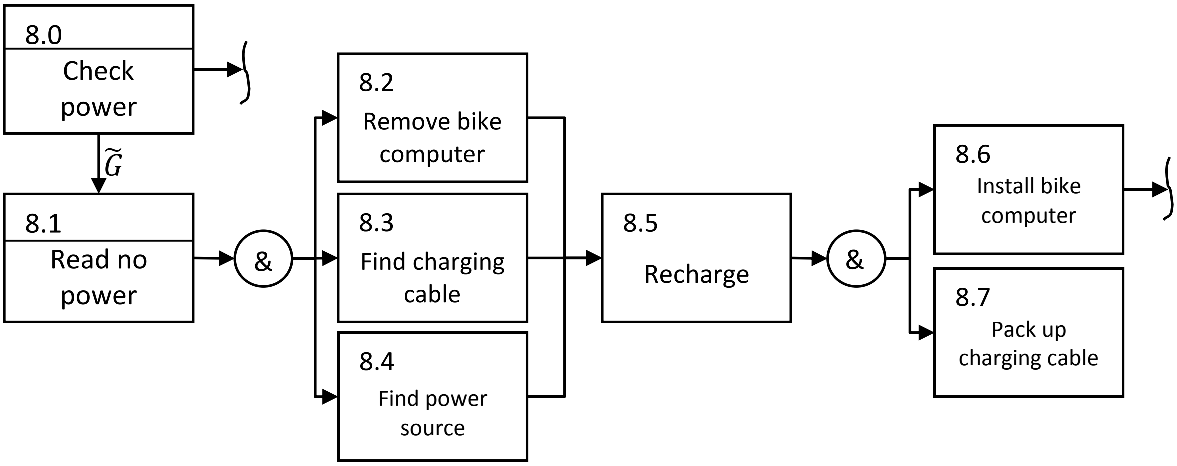


Figure 6 - FFBD for rechargeable battery option

It is evident in Figure 6 that the process for recharging batteries is not as simple as the solar powered bike computer.

3.3.2 Hybrid power (solar panel + rechargeable battery)

The FFBD for checking power in the maintenance flow would be the same as the "OR" combination of the previous two. Hence it is omitted here.

3.4 Functional Allocation

The allocation of functions modularises the whole system into a logical structure of subsystems that we can study more independently. Additionally, it also clarifies the distribution of work between humans and machines (Peter, et al., 1997). For example, in this case, humans are responsible to use UI to give instruction and read outputs, whereas the machine does the rest.

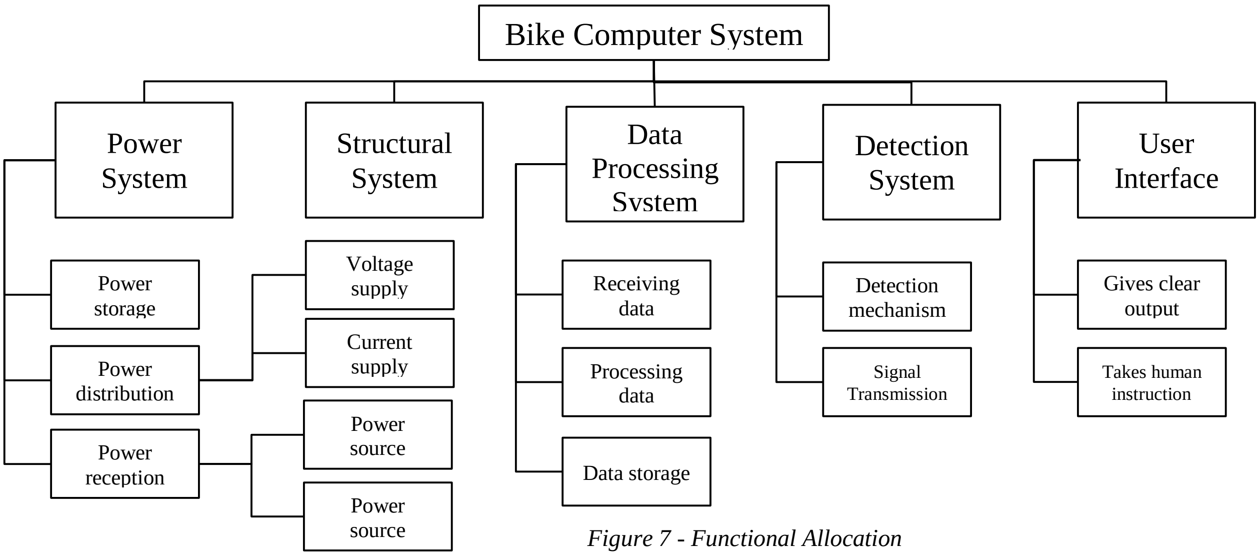


Figure 7 - Functional Allocation

Figure 7 allows us to see the structure of the whole system and to identify subsystems such that they can be studied separately. The power system can be broken down into functions of storing power, distributing power and receiving power. This analysis on the systems and subsystems will help us understand the system interface in the next section.

4.0 Integrating Bike Computer

The functional allocation has identified important subsystems for a bike computer to operate properly. This leads to the integration of those subsystems with inputs and outputs of those subsystems as well as the inputs and outputs of the entire bike computer system.

4.1 System Boundary Chart

Before the construction of the system interface, the system should first have clear boundary between endogenous, exogenous and excluded elements in the bike computer system. The technical way of doing this is by system boundary chart (Browne, 2014).

Endogenous (internal)	Exogenous (external)	Excluded (outside)
Power Detection Data processing Structure User interface	User Bike handle Front wheel Light	External sound Road Rear wheel Brake Other road users

Table 5 - System boundary of a typical bike computer

Here, the five subsystems we identified previously are endogenous. The user, bike handle, front wheel and light are exogenous, but they still affect the normal functionality of the bike computer system. Others are excluded elements.

4.2 Subsystem Definition

The five subsystems of a bike computer have different focus and they achieve different things in the functional perspective. However, they ultimately work together towards one goal, that is, to ultimately bring the user relevant data (average or instantaneous) in a bike trip. The study of the interaction of subsystems would first require their accurate definitions (Table 6).

Power subsystem	The power storage, power distribution, switching on-off (and possibly power reception i.e. solar power) are controlled by the power system. It ensures appropriate amount of power is supplied to where it is needed.
Detection subsystem	The movement of the bicycle is detected. The detection is converted to appropriate signal, which is then transmitted to the data processing system for calculation.
Data processing subsystem	The data processing system is responsible for data processing and data storage. It takes the input from the detection system, then process the data through a series of program. After the algorithm, the processed results are stored in internal memory, and in addition, the results needed by the user are also sent to user interface.
Structure subsystem	The structure system provides physical support to hold the bike computer in place. It also provides protection against external odds (i.e. crash, rain).
User interface	In user interface, the user can give command to the bike computer (e.g. buttons), and the computer can also display readings to the user.

Table 6 - A short description on each subsystem

4.2 System Interface

The interactions between the five subsystems and how they work together as a whole can be effectively illustrated by a Functional Block Diagram (FBD). It is a useful technique for design and controlling a system, because it clearly illustrates the interrelationships between subsystems as well as relevant inputs and outputs. Furthermore, it makes clear how the change of inputs will affect the outputs (Tranoris & Thramboulidis, 2010).

The section that we are particularly interested in is the power system. A FBD for a typical bike computer is shown in Figure 8. Traditional bike computers are powered by a single button cell. The battery is fixed inside the structural frame and sends power to the LCD display and the data processing system. Since we attempt to improve the power system for easier maintenance, it is important to take a note of the input, which is the support from the structural system, and the outputs, which are the power delivered to the LCD display and data processing system and the battery level monitor.

The power section of the FBDs for the three concept designs, namely solar, rechargeable and hybrid power, are shown in Table 7. We can compare them to see how they might interact with other subsystems differently.

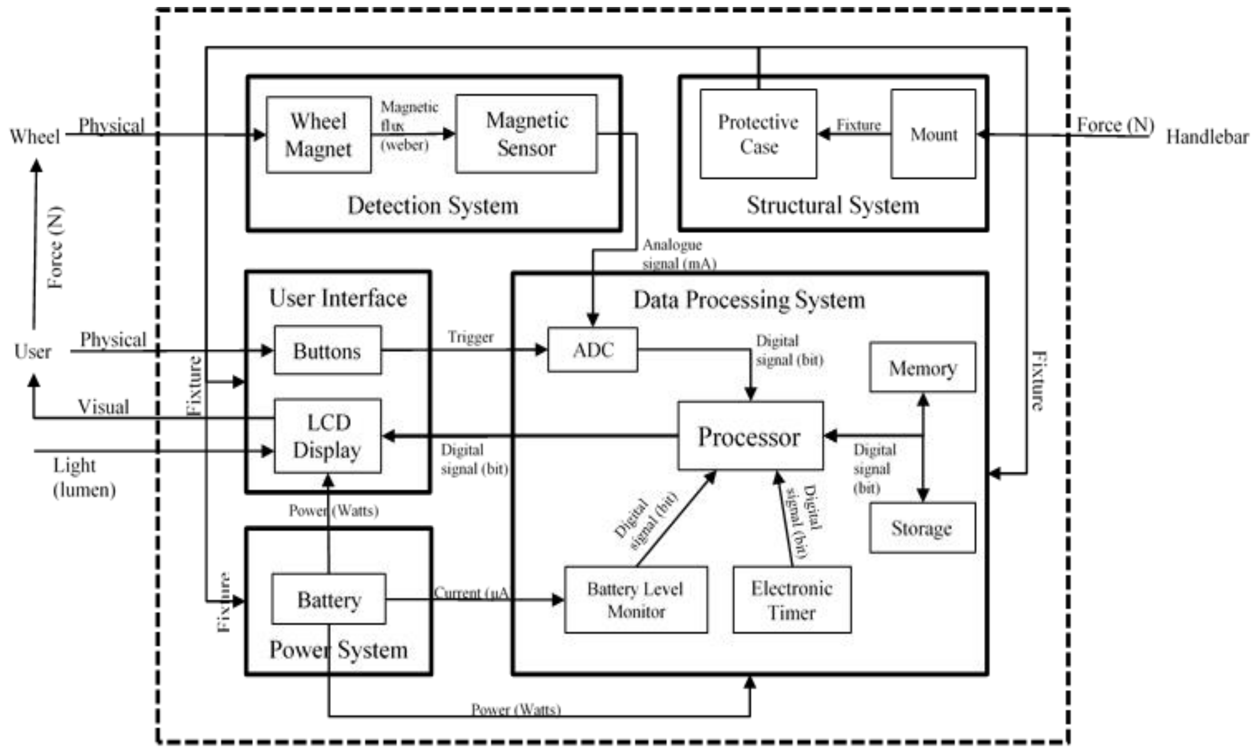


Figure 8 - Functional block diagram for a typical wired bike computer

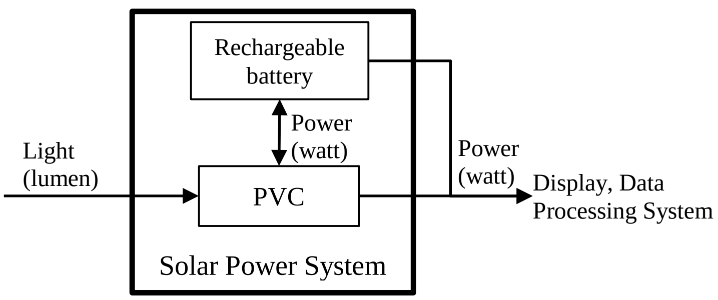
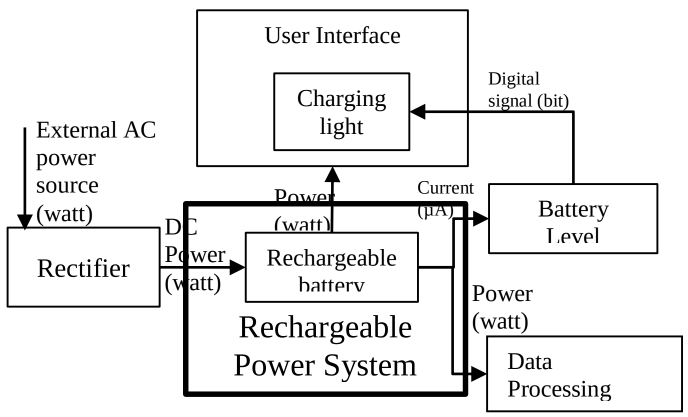
Power system Comparison	**Comment**
	The solar powered bike computer requires adequate light as input. Notably the light is already the input of the User Interface system for reading LCD display. However, for this option, the minimum light intensity requirement may need to increase because more light is needed to power up the system. An internal rechargeable battery and PVC are needed.
	The installation of rechargeable battery requires more components, including, a rechargeable battery (either internal or replaceable), and a charging light. In addition, it requires an external rectifier (AC-DC conversion) and household AC power supply when recharging. This makes the power system have more interactions with other subsystems, the user and some external elements.
Hybrid power system (diagram omitted)	The hybrid power system integrates solar power and rechargeable battery systems. It is omitted here (see discussion below for why).

Table 7 - Comparison of power systems for different designs

The three power systems have distinct characteristics, and it is not difficult to see the advantages and disadvantages of each option. The solar power system is relatively simple and straightforward. It requires no active input effort from the user since the bike computer can be powered on when there is adequate external light. The drawback for this option is that the solar powered bike computer has to exclusively operate during daytime.

The rechargeable battery and the hybrid power systems can operate without light, meaning that the computer can be powered on during the night. However, if it were to be truly usable at night, we may also have to consider adding LED backlight to the display. From the survey and requirement engineering, night usability is not necessary since most bike riders have said that they do not ride in the dark, let alone read a bike computer. The extra maintenance process of the rechargeable battery, and the extra unnecessary complexity of the hybrid system, make them inferior to the solar power system for a normal Australian cyclist.

5.0 System Attributes

The identification of the system interface in the previous step leads to the discovery that, solar powered bike computer may be more suitable for Australian cyclists in the aspects of usability and maintenance. The subsequent step is to find out how a solar power cycling computer should be, and what quality and properties it possesses.

5.1 System Attribute Cascade (solar-powered)

The system attribute cascade is a technique that breaks down quality of a system into more specific system attributes (Browne, 2014). The primary attributes of the solar-powered bike computer have been identified in the customer requirements. Those primary attributes can be met by meeting corresponding secondary attributes, which subsequently can be met by meeting the tertiary attributes. The system attribute cascade is as follows (Table 8).

Primary Attributes	**Secondary Attributes**	**Tertiary Attributes**	**Related Subsystems**
A1.0 Gives correct reading	**A1.1** Accurate detection	**A1.1.1** Correct hardware and software set-ups	Detection, Data processing
		A1.1.2 Minimum distance between magnet and sensor	Detection
		A1.1.3 Strong magnet	Detection
	A1.2 Correct data processing	**A1.2.1** Correct firmware	Data processing
		A1.2.2 Correct execution	Data processing
		A1.2.3 Correct ADC	Data processing
	A1.3 Good signal transmission	**A1.3.1** Digital signal	Data processing

	A1.4 Quick response time	**A1.4.1** Fast processor	Data processing
		A1.4.2 Enough memory	Data processing
A2.0 Low maintenance effort /cost	**A2.1** Component lifespan	**A2.1.1** Long component span	Power, Structure
	A2.2 Long product lifespan	**A2.2.1** Quality components	Structure, Power, Detection, UI, Data processing
		A2.2.2 Reusable components	Structure, Power, Detection
	A2.3 Easy troubleshooting	**A2.3.1** Simple design	Structure, Power, Detection, UI, Data processing
	A2.4 Cheap maintenance	**A2.4.1** Affordable components	Structure, Power, Detection
A3.0 Long maintenance cycle	**A3.1** Durable	**A3.1.1** Wear resistant	Structure, User Interface
		A3.1.2 Fatigue resistant	Structure, User Interface, Power
	A3.2 Long power cycle	**A3.2.1** Large battery capacitor	Power, Structure
		A3.2.2 Efficient computation	Data processing
A4.0 Clear display	**A4.1** Adequate power supply	**A4.1.2** Large light receiving area	Power, Structure
		A4.1.2 Efficient PVC	Power
	A4.2 Large screen	**A4.2.1** Large screen size	User Interface, Structure, Power
	A4.3 Visible reading	**A4.3.1** Good LCD contrast level	User Interface, Power

Table 8 - System Attribute Cascade

The tertiary attributes are linked to related subsystems, which we can use to improve the performance of the attributes. For instance, in the verification and evaluation stages, if one or more design attributes are not met, then we can come back and improve the corresponding subsystems until the attributes are satisfied.

By doing the system attribute cascade, we have found out ‘how’ we can improve the current bike computer design, especially in terms of reducing the maintenance effort and cost. The attributes A2.1-A2.4 define the components to be reusable, high-quality while the design needs to be simple for easy troubleshooting.

To find out if the design of a solar-powered bike computer actually meets those design attributes, we will need to devise tests in the verification stage.

6.0 Verification

6.1 Verification

In verification process, all the attributes found in the system attribute cascade are tested and verified. When a primary attribute is difficult to test, the secondary attributes are tested, or the tertiary attributes. The important aspect of verification is to gather data on the design, which can be used in the evaluation stage for selecting the design and for possible improvement. The testing methods for bike computer attributes are in Table 9.

Attribute of Interest	**Testing Method**
A1.0 Gives correct reading	*Prototype testing (TYPE II)* *Test person: technician* *Pass rate: error < ± 10%* 1. Ride the bike at 5km/h, 10km/h, 15km/h and 20km/h (using a standard GPS device for accuracy). 2. Record the speeds registered by the bike computer at those speeds. 3. Calculate the percentage of error.
A2.1 Long component lifespan	*Proof-of-concept (Type I)* *Test person: Material technician* *Pass rate: predicted lifespan > -10% of average lifespan* 1. Find the material of the component. 2. Test the material and predict the lifespan of the component 3. Compare the lifespan with average
A2.2.1 Quality components	*Analytical/Modelling* *Test person: Engineers/Material specialist* *Pass rate: time before failure > average* 1. Predict how long the bike computer system will fail based on engineering and science knowledge *Prototype Testing (TYPE II)* *Test person: Technician* *Pass rate: time before failure > average* 1. Construct a physical prototype. 2. Test the prototype under normal operational conditions. 3. Record the time that the first component starts to fail.
A2.2.Reusable components	*Analytical/Modelling* *Test person: system engineers/designers* *Pass rate: not reusable component < 1* 1. Sketch all the components on a paper. 2. Count the number of components that have to be replaced per maintenance cycle
A2.3.1 Simple design	*Proof-of-concept (TYPE I)* *Test person: engineers/designers* *Pass rate: number of external components < 4* 1. Rapid prototype all the external components 2. Count the number of external components
A2.4.1 Affordable components	*Proof-of-concept (TYPE I)* *Test person: Technician/Material specialist* *Pass rate: price of any replaceable component < AU$3* 1. Find all the components that may be replaced for maintenance 2. Research the market price for those component

A3.1 Durable	*Operational Testing (TYPE III)* *Test person: Statistician* *Pass rate: average lifespan > 5 yrs* 1. Maintain contact with buyers. 2. Record the information about the lifespan received from buyers. 3. Calculate the average lifespan
A3.2 Long power cycle	*Proof-of-concept (TYPE I)* *Test person: Bike computer technician* *Pass rate: operational time before power resupply > 30 days* 1. Construct a circuit board with resistors that use the same power as the design. 2. Connect the power to the circuit without supplying. 3. Determine the total operational time before power runs empty
A4.0 Clear display	*Proof-of-concept (TYPE I)* *Test person: Visual technician* *Pass rate: minimum distance > 0.5m, max distance > 3m* *1. Illuminate the display of similar type and similar font size (e.g. calculator) with 100lm light.* *2. Find the maximum distance that the bike computer can be read* *3. Repeat step1,2 for 500lm, 1000lm, 2000lm and 4000lm.* *4. Record the minimum distance and maximum distance*

Table 9 - Verification and testing methods

As it shows for A2.2.1 (quality components), there are sometimes more than one ways to test an attribute (e.g. quality components can be tested by proof of concepts or prototyping).

These tests listed in the table are mostly repeatable, that is, when repeated, similar results should be expected. However, some of the tests involve bias. For example, for Attribute A4.0 'Clear display', it is possible that quite different results are expected from different people, depending on the people's eyesight, age, height, and how they define 'readable'.

7.0 Evaluation and Conclusion

7.1 Direct Ranking Method

With the verification data obtained previously, we can evaluate the design by the direct ranking method, in which we compare the three designs against the customer requirements with appropriate importance weighting. The direct ranking matrix is used as follows. It is notable that the matrix should be attached to the right of HoQ, but due to space, it is given below.

Design criteria	Weighting		Solar powered bike computer		Rechargeable bike computer		Hybrid power bike computer		Typical bike computer	
	Rank	Weighting	Relative compliance	Weighted value	Relative compliance	Weighted value	Relative compliance	Weighted value	Relative compliance	Weighted value
Reliability	1	4	5	20	3	12	5	20	5	20

Maintenance	2	3	5	15	3	15	5	15	1	3
User-friendliness	3	2	5	10	3	6	5	10	3	6
Robustness	4	1	3	3	5	5	3	3	5	5
			Total	48		38		48		34

Scale: 5 – exceed compliance, 3 – full compliance, 1 – partial compliance, 0 – no compliance

From the evaluation matrix, we can see that the solar powered design and hybrid powered design share the same result. They have outweighed the other two design in almost every department, except robustness. This is due to the vulnerable solar cells. In terms of fulfilling the top four design requirements, both designs can deliver satisfactory results.

7.2 Evaluation, Discussion and Conclusion

The results show from the evaluation matrix do not necessarily represent the actual operational performance. Realistically, the solar powered and hybrid powered designs are quite different in a way that hybrid powered bike computer is more advanced and can operate without light. From the user perspective, it is not necessary as most people only cycle during daytime where sunlight is readily available. The night operability of bike computers also requires a LED backlight, which consequently further makes the hybrid power unnecessary. Of course, in places lacking sunlight such as inside a tunnel, the solar powered bike computer can only rely on the internal battery.

In terms of maintainability, both solar powered and hybrid powered designs require no compulsory effort from the user. The hybrid design provides greater flexibility to the user, but it adds the unnecessary complexity to the bike computer system at a higher cost (i.e. a simpler system is desired for easy troubleshooting). On the other hand, a rechargeable bike computer requires even more complicated maintenance process and extra maintenance accessories (i.e. charging cable), which is clearly inferior to the other two. Therefore, by carefully comparing and analysing the three designs using systems engineering approach, it is recommended that solar-powered bike computer is the easiest to maintain while it retains similar operation performance from a typical battery-powered bike computer.

This individual research portfolio has used systems engineering design approach to improve the current bike computer. The solar powered bike computer system is found to be the best option that minimises the maintenance process. This consequently meets the design criteria we have set in the beginning, thus meeting the customer requirements that were found in the survey.

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