Finding a great health monitor using System Engineering processes

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Course Name: Systems Engineering Design

Course Code: ENGN2225

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Assessment Piece: Individual Portfolio

Date Submitted: 23rd May 2014

Abstract

This portfolio looks at health monitors from a holistic point of view using systems engineering processes to ultimately decide on the most effective design or a design with suggested improvements. Two devices were tested to get an idea of how health monitors work but since there is such a large range of devices, reviews from other users were taken into account to determine the best solution.

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Introduction

Physical activity has many great benefits as it reduces the risk of health conditions such as cardiovascular diseases, obesity, diabetes, stress and high blood pressure (Bauman A et al. 2002). However, most western societies have abnormally high rates of obesity due to lack of physical activity and over eating (Anshel, M. H, 2006, Billey, H. B., 2002). It is obvious that people need to participate in more physical activity in their daily lives and keep track of their food consumption to reduce these negative health effects. Yet people still choose to live a sedentary lifestyle due to lack of motivation to be physically active, low self-esteem, stress, anxiety, depression and being unorganized. A great range of health and fitness monitors and applications have been introduced to the consumer market as a way for users to keep track of their daily activity. These devices have been presented as a way to introduce physical activity as an enjoyable part of everyday life and not as a chore.

Problem Statement

As people become more aware of the negative effects of living a sedentary lifestyle and more motivated to make a change, they may decide to use a device that can monitor their physical exercise, food intake and track their progress. There are many devices available on the market that can be used for this purpose. These devices range from the basic pedometer that counts how many step are taken each day to activity trackers, smart watches, scales and heart rate monitors. However, since there is such a large range of devices with various functions, it is difficult for a user to know which one will suit their needs. Therefore, it is practical to investigate the functionality of all these devices and highlight the ones that stand out from the rest (Kim, J., 2014).

1.0 System Scoping

1.1 Client meeting and outcomes

An initial meeting with the client was undertaken to discuss the project and her customer requirements. The client is a 25-year-old woman who wants to start living a healthier and more active lifestyle. She has heard about health and fitness monitors and has decided she wants to use one in her endeavour to live a healthier life. She wants to monitor her daily physical activity and get an an idea on her current fitness level and what she could do to improve it. She has a few requirements she has requested for the device.

- It must monitor her physical activity.

- It must be reasonably affordable with a cost limit of $200.
- It must be easy to use as she has never used such a device before and she only knows the basics about health and fitness.
- It must be reliable as she does not want to constantly charge it or have to wait too long to check her progress.

Throughout the systems engineering process used to determine the best solution for the client, the progress of the design will be discussed with the client so that she can give feedback and suggest any changes or improvements.

1.2 Use Case

From the client meeting, a use case was defined. The use case is a summary of the specific situation intended for using the device. For this project, the use case involves the client using the device to monitor her daily activity. Therefore, the device will need to be worn or carried around by the client during the day in such a way that allows it to track her physical activity as well as monitor other physical aspects such as heart rate, elevation, sleep cycle and calorie expenditure. While tracking activity, the device will then need to transform the recorded data into a simple representation of graphs, words or symbols that is easy for the client to understand. Therefore, the basic use case involves the client putting on the device, undertaking daily physical activity and then checking the device to observe her progress.

1.3 System Boundaries

The system is defined by using the systems boundary process. The systems boundary chart shown in Table 1 has been created to determine the aspects of the design that will be considered in the design process. In this situation, the 'system' refers to the health monitor device that is a physical, electronic device. Therefore, within the system boundary includes the components that are internal to the health monitor device such as hardware and software. This is referred to as *Inside* in Table 1.

Outside refers to factors that are likely inputs to the health monitor device such as user interaction and the activity data that is being recorded by the device. Software application refers to the phone and computer applications that are often used in conjunction to health monitor devices. The devices record the data and are able to sync the data to a phone or computer with the purpose of presenting the data in a more understandable way. The power source is included in *Outside* as it input the power to charge the device.

Excluded describes factors that are outside the system and are excluded from consideration as they are outside the scope of the project.

Table 1: Systems boundary chart

Inside	Outside	Excluded
System software	User	Physical disabilities
Display	Daily exercise rate	Mental disabilities
Appearance	Power source	Temperature
Weight	Heart Rate	Weather
Size	Software application	Gender
CPU	Power source	Size of user
Power		Fitness level of user
Circuit board		Moisture
Sensors		Location of user
Wireless communication		
Memory storage		

2.0 Requirements Engineering

The requirements engineering process is used to ultimately translate the customer requirements into measurable engineering characteristics. The first stage of the process is to complete a pairwise analysis to determine the most important customer requirements. The second stage involves translating the customer requirements into design requirements that can then be divided into measureable engineering characteristics. The third stage involves creating a House of Quality matrix with the aim of highlighting relationships between design requirements and engineering characteristics.

2.1 Pairwise analysis

At the client meeting, the client requested certain requirements she would like the design to meet. Her statements were simplified into the following four customer requirements: cost, easy to use, reliable and monitors physical activity. The pairwise analysis allows the importance of these requirements to be established. In Table 2, each customer requirement is compared to the other customer requirements in a pairwise analysis chart.

Table 2: Pairwise analysis

Requirement vs:	Cost	Easy to Use	Reliable	Monitors Physical Activity	Sum	Rank
Cost		0	0	0	0	**4**
Easy to Use	1		1	1	3	**1**
Reliable	1	0		0	1	**3**
Monitors Physical Activity	1	0	1		2	**2**

The pairwise analysis determined the most important requirement of the design is easy to use followed by monitors physical activity, reliable and cost respectively.

2.2 Technical Performance Measures

The customer requirements are nondescript and require subjective measures when testing so in Table 3 they are translated into more specific design requirements. By translating the customer requirements into more descriptive design requirements, the design can be better described in its manifestation. The design requirements are then further divided into Technical Performance Measures (TPM). TPMs are measureable attributes that can be tested to see whether the design meets the design requirements. For each TPM, there is an indication of whether the aim is to increase, decrease or optimise (+/-/◆) the requirement.

It is important that the client's requirements are still being captured by the design requirements and TPMs. The client specified she wanted the device to be "easy to use as she has never used such a device before and she only knows the basics about health and fitness". Therefore, to capture this aspect of the design, the design requirements *software compatibility, simple representation of data* and *can be handled easily* have been included. *Software compatibility* means the device should be compatible with other technology as many health devices can sync their data to mobile phones and computers. The actual health monitors are quite small so this would allow more flexibility when it comes to presenting the data to the user in a way that is easy to understand. This relates to the design requirement *Simple representation of data* and this is very important, as the client has limited knowledge on health and fitness. The design requirement *Can be handled easily* is also important as this is the first time the client is using such a device. It needs to be easy to handle so she can easily turn it on, put it on and choose the settings.

The client also mentioned the device "must be reliable as she does not want to constantly charge it or have to wait too long to check her progress". Therefore, the customer requirement that is must be reliable has been translated into the following design requirements: *Effective data recording, Good battery autonomy* and *Fast processing speed.* These requirements will ensure the device processes information fast and does not need constant charging.

The requirement "monitors physical activity" is quite broad and for the purposes of this project is has been translated into *calculates energy expenditure*. This allows a wide range of techniques to be considered to calculate energy expenditure such as heart rate or daily movement. It is important for the device to measure these attributes accurately to give an accurate calculation of energy expenditure. Therefore, the TPMs refer to the accuracy of the motion and heart rate sensors in the device.

Table 3: Customer requirements and TPMs

Customer Requirement	ID	Design Requirement	Technical Performance Measures	Metric
Cost	DR01-01	Appropriate cost	- Overall Cost	$
Easy to use	DR02-01	Software compatibility	+ Interoperability	Binary
	DR02-02	Can be handled easily	◆ Weight	g
			◆ Physical dimensions	cm
	DR02-03	Simple representation of data	+ Usability	Subjective scale
Reliable	DR03-01	Effective data recording	+ Data accuracy	%
	DR03-02	Good battery autonomy	+ Battery life span	Years
			◆ Battery capacity	mA/hr
	DR03-03	Fast processing speed	+ Data processing speed	Hz
			◆ Memory write speed	Micro/s
Monitors physical activity	DR04-01	Calculates energy exertion	+Heart rate sensor accuracy	%
			+Motion sensor accuracy	%

Translating customer requirements into measurable engineering characteristics has helped to determine what goals to set for the design so that it satisfies the customer requirements.

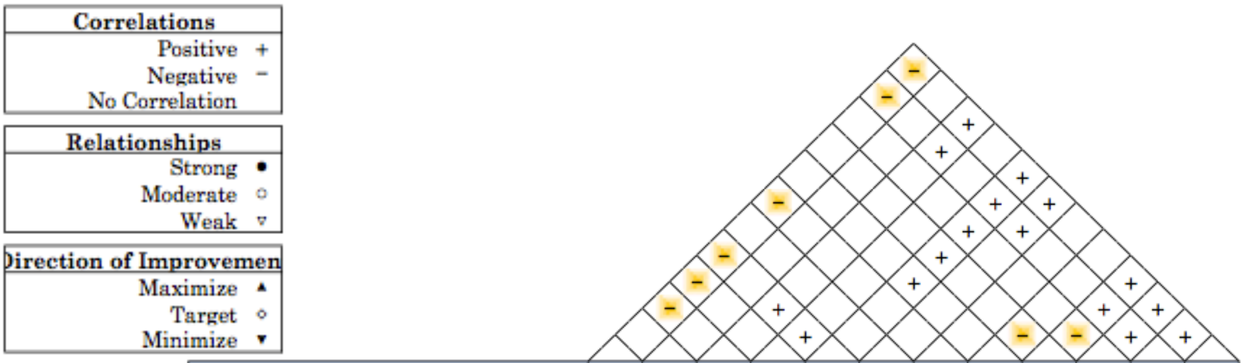
2.3 House of Quality

A House of Quality (HoQ) has been constructed in Figure 1 to determine the level of interaction between both the design requirements and TPMs. The TPMs are referred to as engineering characteristics in this process. The HoQ highlights any important relationships and correlations between design elements. A qualified electronic and IT expert assisted in the assignment of relationships and correlations between the design elements in the HoQ.

The HoQ greatly informs the design as it highlights whether changing certain design aspects positively or negatively impact other design aspects. All of the design requirements have strong relationships with their respective engineering characteristics. However, *Appropriate cost* also has a moderate to weak relationship with the majority of other engineering characteristics.

Looking at the “roof” of the HoQ, overall costs is the most consistently conflicting technical requirement. This is intuitive as optimizing or increasing the performance of other requirements is generally more costly. For example, an optimal device would have a small form factor and require miniaturized components that are generally more expensive. As well as increasing the usability of the device amounts to more labor costs from software and hardware development. Also, batteries with a larger life span and improving the accuracy of the heart rate and motion sensors would again be more costly.

The other correlations between the engineering characteristics are mostly positive. For example, an increase or optimization in sensor accuracy, data processing and memory write speed and battery capacity will all increase the usability of the device.



		Column #	1	2	3	4	5	6	7	8	9	10	11	12
		Direction of Improvement	▼	▲	◇	◇	▲	▲	▲	◇	▲	◇	▲	▲
ID	Relative Importance	Engineering Characteristics / Design Requirements	Overall cost	Interoperability	Weight	Physical dimensions	Usability	Data accuracy	Battery life span	Battery capacity	Data processing speed	Memory write speed	Heart rate sensor accuracy	Motion sensor accuracy
DR01-01	8	Appropriate Cost	●	▽	▽	▽		○	▽	○	○	▽	▽	▽
DR02-01	3	Software compatibility	▽	●			○							
DR02-02	1	Can be handled easily			●	●	○							
DR02-03	2	Simple representation of data					●	●						
DR03-01	5	Effective data recording	○					●						
DR03-02	6	Good battery autonomy	○						●	●				
DR03-03	7	Fast processing speed	○	▽				○			●	●	▽	▽
DR04-01	4	Calculates energy exertion	▽								▽	▽	●	●
		Metric/TPM	$	Binary	g	cm	Scale	%	years	mA/hr	Hz	ms	%	%

Figure 1: House of Quality

Considering the customer requirements and how they ranked in the pairwise analysis, cost was the least important. Therefore, an increase in overall cost would be acceptable in order to make the device more easy to use, reliable and effectively monitor physical activity. Therefore, from the HoQ, it can bee seen that all design requirements can be increased or optimized to a certain extent as long as it fits within the maximum allowed budget of $200.

3.0 System Function Definition

3.1 Concept Generation

Once the customer and design requirements had been established, a whole of system brainstorming approach was used to generate several concepts from the design requirements. Concepts were brainstormed for each design requirement as shown in Table 4.

Table 4: Concept generation table

Customer Requirement	Design Requirement	Concepts
Cost	Appropriate cost	Finding existing device that meets customer requirements or improving existing technologies
Easy to use	Software compatibility	Bluetooth enabled, data sharing with other users, USB connection, cross compatibility between other applications
	Can be handled easily	Lighter materials, smaller size, easy to hold, worn on wrist, hip, in pocket
	Simple representation of data	Display on device, display graphs/information on phone or computer applications, vibration alert device, haptic feedback
Reliable	Effective data recording	Accelerometer, barometric pressure sensor, pedometer, heart rate monitor (light sensors, brain activity sensors)
	Good battery autonomy	Lithium ion battery, rechargeable, easy to charge, cordless charge (inductive charging), cord charging, standard batteries
	Fast processing speed	High quality hardware components
Monitors physical activity	Calculates energy exertion	Tracks elevation, daily number of steps, heart rate, sleep cycle, scales, heart rate monitor watches, brain activity scanners, activity tracker, smart watches, phone apps

From the concept generation table, to find a device that is an appropriate price, the most feasible options are to either use or improve existing technology instead of design and manufacture a completely new design. Therefore, when looking at existing technology, all the concepts that have been generated based on the design requirements will be considered. There may be a device available that has all the features required but if not then a design can be chosen with suggested improvements.

3.2 Functional Flow Block Diagrams

Functional analysis was completed for using a general activity tracker, a type of health monitor that tracks daily physical activity. A functional flow block diagram (FFBD) is a systematic diagram broken into functions and sub functions. The FFBD has been developed to show the process of using a health monitor when undertaking physical activity. Figure 2 shows an FFBD showing the basic top level of the process with a sublevel that includes a maintenance flow block diagram (MFBD). The MFBD illustrates how to troubleshoot when the device does not start (no go G'). FFBDs are easy to follow and can highlight strengths and weaknesses of the design and the way it is intended to be used.

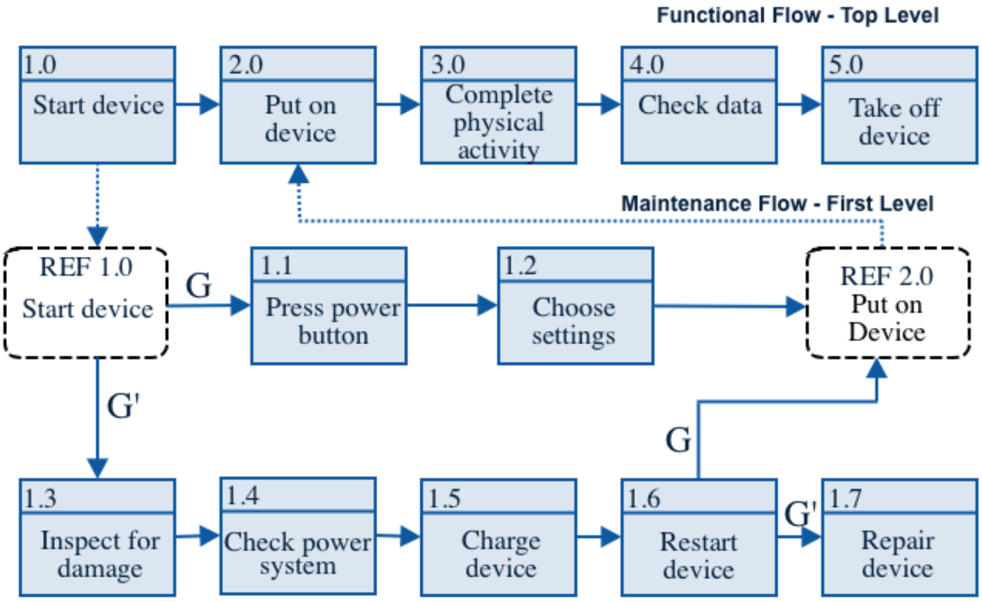


Figure 2: FFBD showing maintenance level when device does not start

Figure 2 shows it is relatively simple to put on a working activity tracker, as it only requires pressing the power button, choosing settings and putting it on.

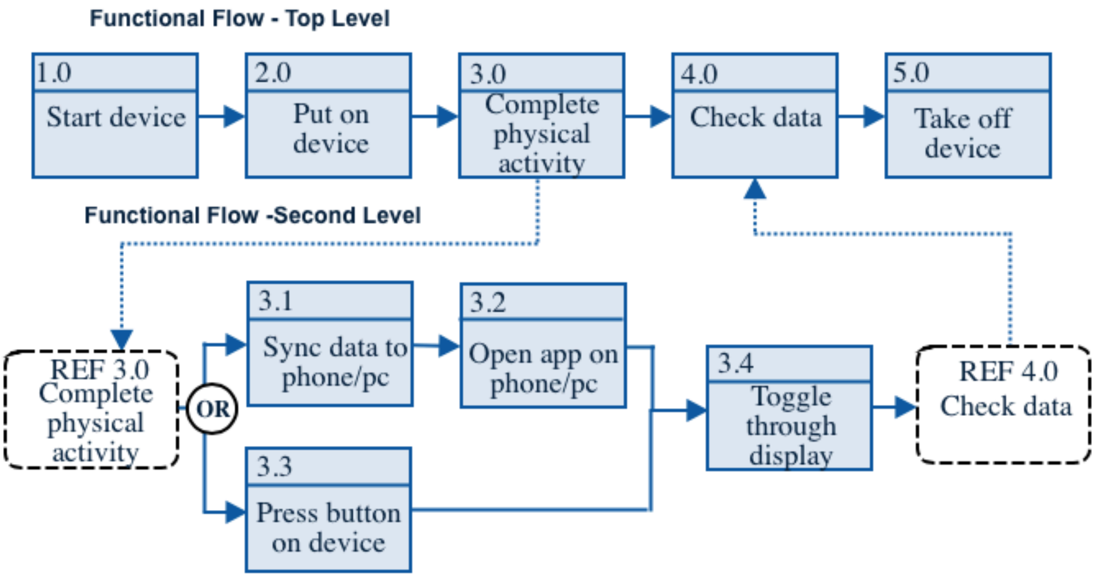


Figure 3: FFBD showing two data representation options

Figure 3 shows the sub functions of using the activity tracker after completing physical activity. The sub level here shows there are two options the user can choose from to check their progress data. Two options allows a lot more flexibility as the most important data can be shown on the actual health monitor and a more in depth analysis including tips and feedback could be included in the phone or pc app.

3.3 Concept classification

The concepts from the concept generation stage have been put into a flow chart (Figure 4) and classified based on where they are worn on the body. The five different classifications of health monitor devices are worn on the wrist, chest, hip/pocket, and head or not worn on the body. Examples of concepts from these categories are also shown. The green objects have been selected for further consideration whereas the red objects have been eliminated from further consideration. Head devices such as brain activity scanners do not meet the customer requirements of cost, easy to use or monitors physical activity. The 'not worn on body' classification has also been excluded as concepts under this category only record data for the time of use and this does not meet the requirement of monitors physical activity. Chest, wrist and hip or pocket devices have a much larger range of options. They generally meet all the customer requirements but further investigation will need to be undertaken to determine which devices have all the required features.

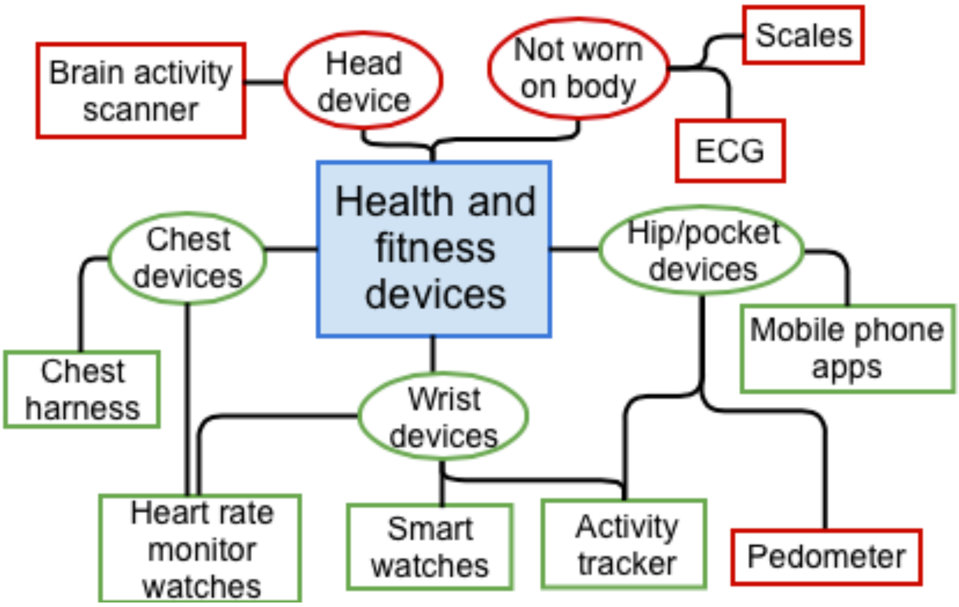


Figure 4: Concept classification diagram

4.0 Subsystem Integration

4.1 Model Boundary Chart

A model boundary chart is a structured way of brainstorming the important and excluded aspects of the system. The system boundary chart from the system scoping stage has been used with the internal elements of the system being described in subsystems as determined in the next functional allocation stage. The internal elements with their associated subsystem and the external components are shown in Table 5.

Table 5: Model boundary chart

Internal	Subsystem	External
System software	Operating system	User
Display	User interface	Daily exercise rate
CPU	CPU	Power source
Power	Power	Heart Rate
Sensors	Sensors	Software application
Wireless Communication	Communication	Power source (USB port)
Memory storage	Memory storage	
Circuit board*	Hardware*	
Appearance**		
Weight**		
Size**		

*The hardware subsystem is excluded from the functional allocation and FBD as the all the other subsystems are part of the device's hardware.

**These factors are not parts of the device that have inputs/outputs to the other subsystems so they are also excluded from the FBD.

4.2 Functional Allocation

The health monitor system is broken down into systems and subsystems as shown in Figure 5. The system operator (user) is external to the system but is a vital element in the functioning of the system. The software application has also been defined as outside the system but is included in the functional allocation as it is part of the interaction between the device and the user. The information processing system refers to the internal elements of the health monitor system that process the information from the sensors in the data recording system.

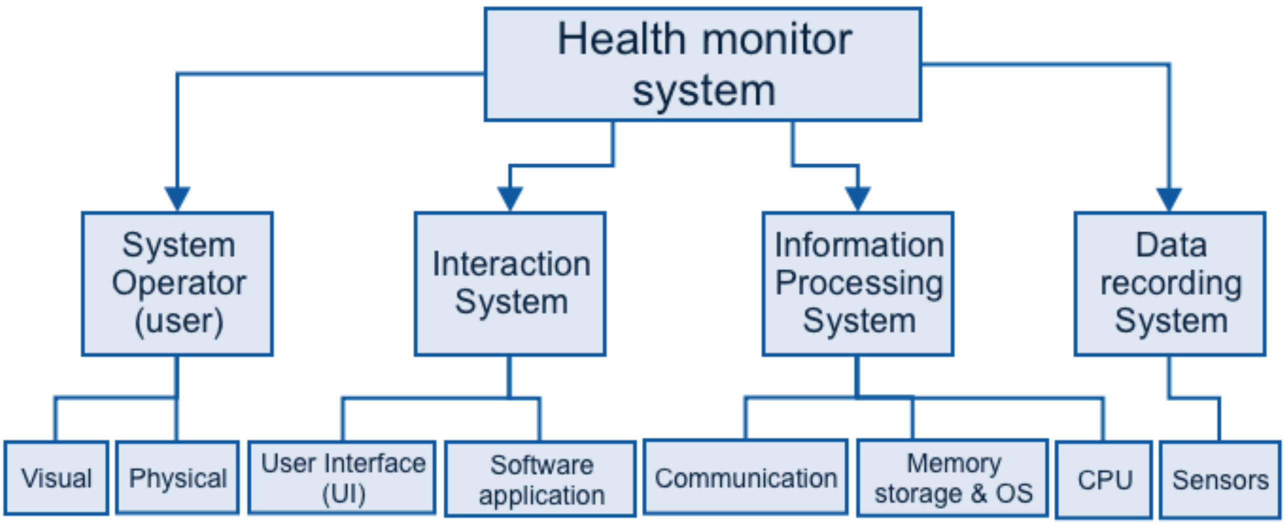


Figure 5: Functional allocation

The functional allocation has helped determine the subsystems of the health monitor device that will be used in the functional block diagram (FBD) in the next stage.

4.3 System Interface (FBD)

An FBD has been created in Figure 6 to understand the layout and interactions between external and internal elements in the system. All the subsystems within the health monitor system have inputs and outputs to other subsystems via data transfer measured in gigabytes shown by the solid blue arrows. The larger arrows show inputs and outputs from factors outside the system. The FBD shows the user interacts with the user interface (UI) subsystem physically for input and visually for output. The user's physical activity data is recorded in a digital format by the sensor subsystem. The data can then be transferred to the computer processing unit (CPU) subsystem where it can then be sent to any of the other internal subsystems. The memory storage subsystem includes the devices operating system (OS) and data is recorded and stored here. The power system provides power to the processing subsystem as well as all other elements in the system and can be charged via a USB port. The communications subsystem can either sync data received from the CPU via the USB port or through a wireless transfer, most likely blue tooth, directly to the software application.

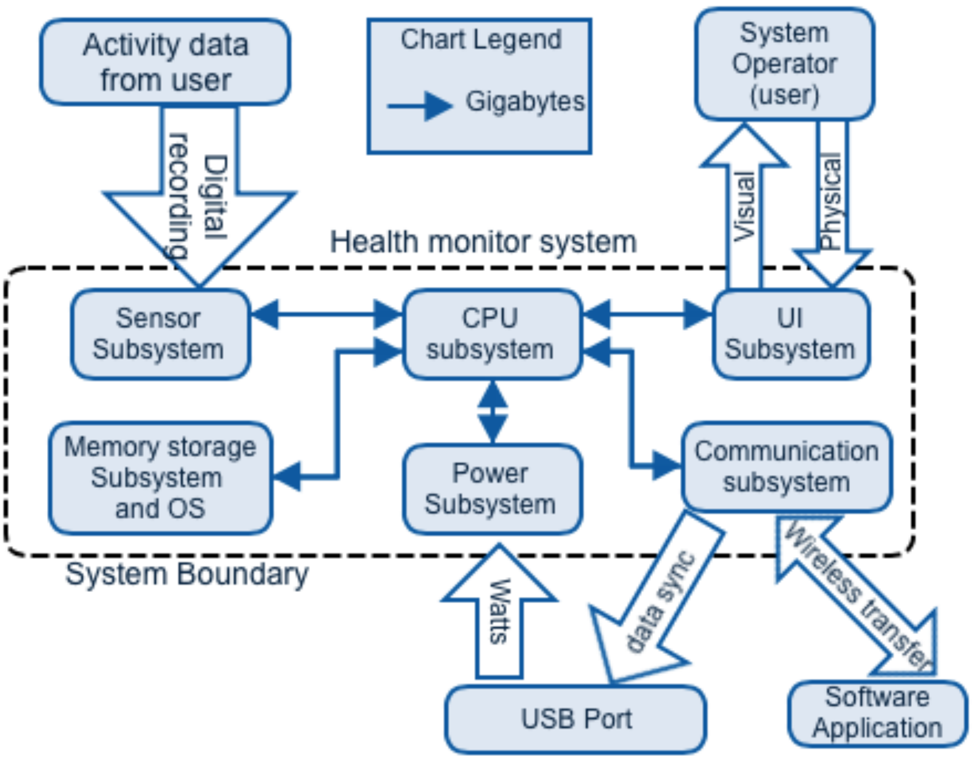


Figure 6: Functional flow block diagram (FBD)

5.0 System Attributes

5.1 Attributes Cascade

An attribute cascade as been developed in Table 6 to relate the customer requirements to the system interface. The attributes are created by considering how each design requirement will be achieved.

Table 6: Attribute cascade

Primary attribute	Secondary Attribute	Tertiary Attribute	Related Subsystem
A1.0 Software compatibility	A1.1 Cross-platform compatibility	A1.1.1 Compatible with all computer OS	COMM
		A1.1.2 Compatible with all phone OS	COMM
	A1.2 Universal connectivity	A1.2.1 USB connectivity	COMM, POW
		A1.2.2 Bluetooth connectivity	COMM
A2.0 Can be handled easily	A2.1Small form factor	A2.1.1 Multifunctional buttons	UI, PROS
		A2.1.2 Miniaturized electronic circuitry	HARD
		A2.1.3 Miniaturized battery	POW
	A2.2 Made of grippy materials	A2.2.1 Rubber sections	HARD
	A2.3 Wearable	A2.3.1 Belt clip	HARD
		A2.3.2 Wristband	HARD
A3.0 Simple representation of data	A3.1 Intuitive data representation	A3.1.1 Use familiar icons, words and graphs	UI
A4.0 Calculates energy exertion	A4.1 Measures heart rate	A4.1.1 Light sensors	SEN
		A4.1.2 Electrical signal sensor	SEN
	A4.2 Measures daily steps	A4.2.1 Pedometer	SEN
		A4.2.2 Accelerometer	SEN
	A4.3 Measures elevation	A4.3.1Barometric pressure sensor	SEN
	A4.4 Measures sleep movement	A4.4.1 Accelerometer	SEN
		A4.4.2 Brain wave sensor	SEN
A5.0 Fast processing speed	A5.1 Fast CPU	A5.1.1 Fast clock speed	CPU
		A5.1.2 Low power	CPU
A6.0 Good battery autonomy	A6.1 High performance battery	A6.1.1 Lithium ion	POW
		A6.1.2 Good capacity vs size	POW
A7.0 Effective data recording	A7.1 Precision accelerometer	A7.1.1 Good quality sensor	SEN
	A7.2 Precision heart rate monitor	A7.2.1 Good quality sensor	SEN
A8.0 Appropriate cost	A8.1 Low production cost	A8.1.1 Low cost materials	ALL
		A8.1.2 Simple design	ALL
		A8.1.3 Makes use of existing technology	ALL
	A8.2 Low maintenance cost	A8.2.1 High production quality	ALL
		A8.2.2 Bug-free software	ALL

LEGEND: UI = UI subsystem, COMM= Communication subsystem, POW = Power subsystem, HARD = Hardware subsystem, SEN = Sensor subsystem, ALL = All subsystem, CPU = CPU subsystem

The attributes cascade has highlighted how the requirements relate to the subsystems of the device. The requirement appropriate cost is affected by all the subsystems. The other requirements are mainly effected by particular subsystems such as calculates energy exertion and effective data recording relates to the sensor subsystem, simple representation of data is related to the user interface subsystem, good battery autonomy relates to the power system and software compatibility relates mostly the communication subsystem. This outcome means that to meet certain design requirements, subsystems can be assessed or improved individually. For example, when comparing devices and looking at how simple the data is represented, only the user interfaces of the different devices need to be compared.

6.0 Verification and Evaluation

6.1 Design validation

Design verification is the process of determining whether or not the proposed design meets the customer requirements, design requirements and technical performance measures which were devised in the requirements engineering process. There are a number of different methods that can be chosen to test the attributes of the design from the systems attributes stage. The four types of testing are proof-of-concept testing, prototype testing, operational testing and support testing. Since the designs that are being considered are either existing devices or improvement of existing devices, operational testing is the most applicable stage of testing to use. The following testing procedure has been undertaken to test the eight design requirements for two devices, Withings Pulse and Fitbit Flex.

Testing procedure: One week usability testing

Attributes: A1.0-A8.0

Tester: User

Procedure outline: The user is to use each device everyday for one week and comment on how well the device meets each of the eight attributes.

Pass/fail criteria: The only quantitative limitation is a maximum cost of $200. The other attributes will be compared between devices to find a standard level the chosen device must meet.

Withings Pulse Trial

After using the Withings Pulse, the tester found all the attributes were reasonably met except it appeared the accuracy of the data measurement could be more accurate as resting heart rate measurements varied greatly for no apparent reason.

Fitbit Flex Trial

The tester also found the Fitbit Flex was of reasonable standard and met the majority of attributes. However, the actual device only has a small light display to indicate progress and was not as informative as the LED information display on the Withings Pulse.

Other designs such as heart rate monitor watches cannot be tested, as there were none available to test. However, based on reviews of the devices, heart rate monitor watches are very accurate at measuring heart rate and calorie consumption. A downside to heart rate monitors is they involve using a chest strap to measure the heart rate and this could be uncomfortable and tedious for the user to put on. Smart watches have a lot of potential and could eventually include all the great features required to measure physical activity. However, smart watches are still being developed. Activity trackers have a lot of potential as they make use of mobile phone and pc applications to represent the data to give a detailed analysis of physical activity and other data can be entered such as calories consumed to get an even better idea of daily progress.

6.2 Design evaluation

The design evaluation process involves comparing designs against each other to see how they rank against the customer requirements. A single design has not been chosen at this stage, as there is such a wide range of health monitor devices available. For the evaluation matrix produced in Table 7, three general devices are compared. An activity tracker can be worn on the wrist or hip, they are reasonably priced and very easy to use as they only require putting on and checking progress either on the device itself or on a connected software application. They are reliable as their battery capacity can last around two weeks. They are fairly accurate when it comes to monitoring physical activity, however not as accurate as the heart rate monitor watches. Heart rate monitor watches are also affordable but not as easy to use as activity trackers as they require attaching a chest strap to measure the heart rate. The third option is a smart watch that tries to incorporate not only activity tracking but also all the aspects of a phone such as messaging and calling. The majority of software in these smart watches for monitoring physical activity is not as effective as the other two options.

Table 7: Evaluation matrix

			Option 1 Activity Tracker		**Option 2 Heart rate monitor watch**		**Option 3 Smart watch**	
Design Requirements	Rank	Weighting	Score	Weighted Value	Score	Weighted Value	Score	Weighted Value
Cost	4	1	3	3	3	3	3	3
Easy to use	1	4	9	36	3	12	3	12
Reliable	3	2	3	6	3	6	3	6
Monitors physical activity	2	3	3	9	9	18	1	3
				54		39		24

The evaluation matrix shows the three options comply with all the customer requirements except the smart watch does not comply with monitoring physical activity. Therefore, this design should be excluded from consideration. However, as smart watch technology develops, it may be a more feasible option in the future. Activity trackers have the highest score at 54 with the heart rate monitor watch close behind with 39. The activity tracker exceeds compliance with the most important customer requirement easy to use. However, the second most important design requirement, monitoring physical activity, has exceeded compliance with the heart rate monitor watch. Therefore, a trade off can be observed as the device is more accurate at monitoring physical activity, its complexity increases making it harder to use.

6.3 Design selection

The design that has been selected using the systems engineering processes for the client is an activity tracker. This design meets all the clients' customer requirements, in particularly the requirement that the device must be easy to use. As activity trackers connect to software applications on phones and computers, the data can be analysed and represented in a simple format making it easy for the client to understand. Other useful information can also be included as well as motivation and encouragement to help the user reach their goals. Activity trackers usually are under $200 so that is under the client's budget. They are also accurate enough at calculating energy expenditure by tracking daily steps and sleep patterns with an accelerometer and elevation with a barometric pressure sensor. Some activity trackers even track body temperature and moisture. Activity trackers are reliable as they have a good battery autonomy and fast processing and memory storage speed so the client won't have to constantly charge the device or wait too long to check her progress. A specific device still needs to be chosen so another client meeting will be held to present the suggested design of an activity tracker to the client.

7.0 Design communication

The design will be communicated with the client through a client meeting. Visual aids will be used to demonstrate the features of activity trackers and how they are used. There are many videos online that companies have made to promote their particular brand so some of these will be shown to the client so she can get an idea of the type of activity monitor she would like to use. Based on her feedback, a specific device will be chosen and assessed against the requirements, performance measures and system attributes to ensure the design still meets her original design requirements.

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