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A Smart Walking Stick for Elderly People – PART 1 : Market Survey and Concept Generation

Anas Abdul Rahman[a], Firdaus Azman[a], Ai'sya Mohd Adzha[a], Syuhada Ahmad Farid[a], Syakur Mohd Sabri[a], Noradina Nordin[b], Ayu Abdul-Rahman[c]

[a]Mechanical Engineering Program, Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Pauh Putra Main Campus, 02600 Perlis, Malaysia
[b]University Health Centre, Universiti Malaysia Perlis, Pauh Putra Main Campus, 02600 Perlis, Malaysia
[c]Department of Mathematics and Statistics, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 UUM, Sintok, Kedah, Malaysia

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Abstract: This paper is the first of two, which focuses on the use of walking sticks as the mobility aid tools that are used by the elderly or people with mobility limitations to maintain their balance and stability while they carry out their daily activities, enabling them to live a life of independence. With the advancement of technology, a modern walking sticks can be found aplenty on commercial platforms. However, choosing a suitable walking tool may not be easy. Ease of function, specific features and value for money are among important factors that influence potential users in choosing their walking aid. For this project, a Smart Walking Stick is developed. It is equipped with an auto fall alarm sensor and a Global Positioning System (GPS) is used to detect the location and later, send notifications to closely related people via mobile devices in the event of an emergency. This newly developed Smart Walking Stick aims to be a device that can improve mobility and accessibility. Notably, this device is also developed with the desire to contribute to Malaysia's IR4.0 and Sustainable Development Goals (SDG) ambitions, specifically in helping people with physical difficulties that may have barriers to mobility. Along with the development of digitalization, this innovation also links the user with the Internet of Things (IoT) to increase their safety. This paper covers detailed results from the market survey conducted and concept generation for a novel walking stick. The second paper covers comprehensive design configuration and technical analysis that was performed on the prototype.

Keywords: *Walking aid, Alarm sensor, Grid Positioning System (GPS), Internet of Things (IoT), National Fourth Industrial Revolution (4IR), Mobility issues*

1.0 Introduction

1.1 Overview

People with physical disabilities may have significant barriers to mobility, which can prevent them from performing their daily life or other activities, including moving and walking. Most of These people depend heavily on their families and other people to help them with their daily tasks. The limitations in their mobility, due to problems such as muscle weakness and loss of body balance may also deter them from social interactions and participating in social activities. Hence, this project aims to tackle the mobility limitations faced by people with mobility issues. In this project, the target user is specifically directed to elderly people aged 60 years and older.

Corresponding Author: Anas Abdul Rahman, Mechanical Engineering Program, Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Pauh Putra Main Campus, 02600 Arau, Perlis, Malaysia, anasrahman@unimap.edu.my

A smart walking stick has been designed as an assistive device that can help improve the user's mobility by increasing the base of support and balance as well as increasing their activity and independence with advanced—information technology. A typical walking stick or cane only helps to support the user's mobility. However, this smart walking stick is equipped with various technologies, such as auto-fall alarm sensors and tracking systems such as the Global Positioning System (GPS) to detect the location of users after the activation of alarm sensors. Significantly, the smart walking stick can send notifications to relatives through devices as soon as an emergency happens. In this project, NodeMCU8266, which is an open-source development board, was used to process the sensor detected and send it to the relatives.

Thus, this walking stick will be a device that can improve accessibility and mobility that can be linked with the IR4.0 and Sustainable Development Goals (SDG) to solve this crucial problem. This project was undertaken with Sustainable Development Goals (SDG) in mind, specifically concerning goal no 9 which is to develop quality, reliable, sustainable, and resilient infrastructure to support human well-being, focusing on affordability and equity [1]. Likewise, this project also aims to support domestic technology development, research, and innovation in developing countries, including by ensuring a conducive policy environment for industrial diversification and value addition to commodities. Correspondingly, this project introduces and promotes new technologies, as well as facilitates and enabling the efficient use of resources. Significantly, this current work has managed to come up with new walking sticks innovation based on the targeted people's requirement.

1.2 Background

According to the report from the World Health Organization (WHO), almost 28-35% of the elderly at 65 years old and older fall every year, and this number rises to 32-42% among people over 70 years of age [2]. Injuries caused by falling have become the dominant reason for pain, disability, loss of self-caring ability, and even premature death. The walking stick is such an important device to assist the elderly in "walking" and "strolling". It has been an indispensable tool for some of them in everyday life, particularly when they move about. Furthermore, a walking stick can effectively prevent them from falling because of their weak muscle power, visual decline, balance loss, improper navigation indoors and outdoors, as well as environmental obstacles.

Therefore, to cater to the growing demands of the elderly community, especially in Malaysia, various types of sticks or canes have been produced, namely a wooden cane, a folding cane, a quad cane, and a seat cane as shown in Table 1.1. All of these sticks are already on the market. However, these sticks still have certain drawbacks and weaknesses. Hence this project aims to propose a new walking stick concept to be used by the elderly community to help them move around in unfamiliar environments and monitor their condition everywhere.

The purpose of this project is to design and develop a smart walking stick that has distinct features currently not present on a conventional stick to help users to move independently and confidently. By improving the functionality of a walking stick, elderly people can live a better life because these sticks can provide them with a feeling of safety, security, and comfort no matter where they are.

Table 1.1 Type of canes and their respective description

Types of cane	Description
 Wooden cane [3]	Wooden canes are composed solely of wood materials. While many canes on the market are made of metal materials, these canes do not contain any metal. The wooden canes come in different varieties and may be made of various wood species [4].
 Folding cane [5]	Folding canes allow the user the ability to tuck the cane away when not in use and just as easily, deploy it at a moment's notice [6].
 Quad cane [7]	A quad cane is a mobility device that aids walking and mobility. It is similar to a standard cane, but it has a metal base on the bottom with four small feet that extend from the base. These feet have rubber caps that help reduce slippage on the floor [8].
 Seat cane [9]	The sitting cane design is a cane with a folding seat. This design is for elderly people when they need a portable chair to take to events, or they just want a convenient way to stop and take a rest on a long walk [10].

1.3 Problem Statement

A walking cane is supposed to be used by elderly people having difficulties walking from one place to another place. As technology advances and grows, the design of the walking cane has been improved to fulfil customers' satisfaction. From our perspective, elderly people need a walking cane that can help them walk. For instance, issues such as users having an emergency from falling and having to call for help from people surrounding them are common. They might be in a serious situation because of their age and other medical conditions.

Furthermore, most of the commercial walking canes are not stable for elderly people who are always wobbling while they are walking. As a result, it will be dangerous for them as they can fall because their walking cane is not stable [11]. Moreover, most elderly people cannot stand up from their seats easily. Because of their weak legs, they must hold on to something when getting up from a sitting position [12].

Meanwhile, the current walking cane designs are very basic and do not have features that can detect the location if something bad happens to them. Finally, the standard walking cane designs do not reflect technological advancement Hence, in this study, a product that can address the aforementioned issues is the main focus.

1.4 Objectives

The walking stick or cane in the market is lacking some features related to safety, security and comfort for elderly people. This project aims to identify the existing problems and provide relevant solutions.

This project covers:

i. Designing and embedding electronic intelligent features into the existing walking sticks design with a tracking system and auto-fall alarm sensor.
ii. To design an ergonomic and comfortable walking stick to improve the quality of life for elderly people.

1.5 Scopes

The scope of this project will be as follow:

- The target is the elderly people that have difficulties walking with the standard stick.
- Employing technology based on the internet of things (IoT) such as the GPS and to address the IR 4.0 and SDG.
- Focus to make a walking stick with a seat and knee bar with high durability to support the weight while sitting, standing up and walking.

2.0 Need Analysis

2.1 Market Survey

In this project, the target market includes users of walking sticks who own a walking stick or cane for walking purposes. Besides the user, a person that is closely related to the users is also a part of the targeted group in collecting relevant information and feedback. Table 2.1 exhibits the existing products and their descriptions. The first product, Foldable Walking Stick, is a walking stick that focuses on the customer's convenience. The walking stick can be folded using the screw mechanism, is light in weight with aluminum alloy as well as easy to bring along anywhere.

The second product is the Foldable Crutch Cane Walking Stick Seat Stool Chair. This walking stick combines with a seat that can be used to sit down to while in the middle of walking. Plus, it can be easily folded, making it convenient for storage purposes. However, because the product is made from plastic, specifically the seat, there is a maximum allowable limit on customers' weight. Next, the 'U' shape of the handle makes it easier to either hold or hang the product. However, since its height cannot be changed, this product may not be suited for some people.

Table 2.1 Benchmarking of existing product

No.	Product Name and Features	Pricing (RM)	Picture
1.	**Foldable Walking Stick** Height product: 84 – 93 cm Product weight: 0.28 kg Material: Aluminum alloy and rubber Features: -Can be fold -Grip handle	20.00	 [13]
2.	**Foldable Crutch Cane Walking Stick Seat Stool Chair** Height product: 75 cm Product weight: 70 kg Material: Aluminum and stainless steel Features: -Have seat -Comfort handle	19.80	 [14]
3.	**Stainless Steel Walking Stick Quad Cane** Height product: 68 – 95 cm Product weight: 2.0 kg Material: Stainless steel with synthetic rubber support Features: -Have quad base and stable -Comfort handle	20.00	 [15]
4.	**Intelligent Electronic Walking Stick Walker Aluminum Alloy T - Straight Handle** Height product: 64 – 97 cm Product weight: 0.5 kg Material: Aluminum alloy and polycarbonate Features: - Have radio, alarm, LED light, Power button	130.00	 [16]

Thirdly, the Stainless-Steel Walking Stick Quad Cane is a walking stick with a quad base type that can give more support for the user's stability when walking. Plus, with the adjustable height, the walking cane is suitable to be used for various groups' average height. The synthetic rubber support on the base gives more support to prevent the user from slipping. Finally, the last product is Intelligent Electronic Walking Stick Walker Aluminum Alloy T-Straight Handle. In comparison to other walking sticks, this product is equipped with advanced features such as LED light, radio, alarm, and button. Aside from the adjustable height, the

walking stick is also light in weight. This last product is an example of a walking stick with futuristic safety components and convenience for users to handle and depend on.

Table 2.2 shows the comparison based on customer requirements. Six aspects were compared among these four products, namely maximum height, durability, easy to handle, long life, features and cost. The range of scoring is from 1 to 5 which indicates bad and good for scores '1' and '5', respectively. This scoring is based on the descriptions of corresponding products as shown in Table 2.1.

Table 2.2 Comparison based on customer requirement

Customer Requirement	Foldable Walking Stick	Foldable Crutch Cane Walking Stick Seat Stool Chair	Stainless-Steel Walking Stick Quad Cane	Intelligent Electronic Walking Stick Walker Aluminum Alloy T-Straight Handle
Maximum Height	4	3	5	5
Durability	4	3	4	4
Easy to handle	3	3	5	4
Long life	4	4	5	3
Features	3	3	3	4
Cost	5	5	5	2

2.2 Design of Market Survey

This survey was conducted using a questionnaire. The questionnaire contains a set of questions that has been created to gather information and for statistical study. For the market survey purposes, the questionnaire was divided into four sections: (i) demographic profile, (ii) general overview, (iii) problems and (iv) solutions. The questions constructed in this survey are a mixture of Likert scales, multiple choice questions and some close-ended questions. This survey was intended to gather information on walking stick usage among senior citizens.

The first part of the questionnaire is the demographic profile of the respondent. The demographic profile contains the respondents' personal information such as their occupation, age, and gender. The information provided would help the researchers to understand more about the respondents.

The second part of the questionnaire concentrates on the respondent's situation and environment. Respondents were required to respond whether they are using a walking stick in their daily tasks.

The third section of the questionnaire focuses on common problems faced by the users (of the walking stick). There are nine questions in this section such as whether the users (of the walking stick) have to sit for a while, whether their legs feel weak easily and if the users frequently wobble. To collect feedback, Likert scale questions were employed.

Finally, the last section is the proposed solutions by the respondent if or once the smart walking stick has been created. These questions correspond to the customer requirements whereby the inputs were implemented on the House of Quality (HOQ).

2.3 Survey Analysis

A survey had been conducted to collect the customer needs and requirements to obtain reliable data regarding the smart walking stick for elderly people. 101 responses from various backgrounds had been collected for this project. Figure 2.1 to 2.15 present the data based on the survey conducted.

2.3.1 Demographic Profile

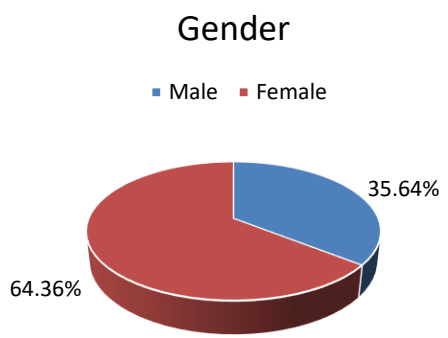


Figure 2.1 Percentage of respondents by gender

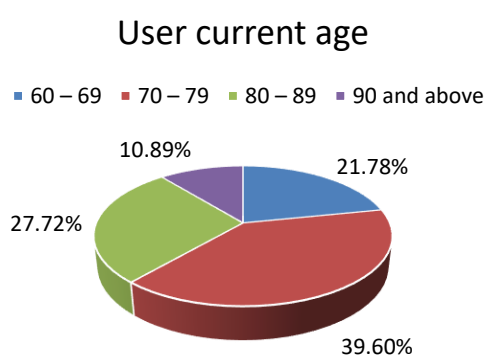


Figure 2.2 Percentage of respondents by user current age

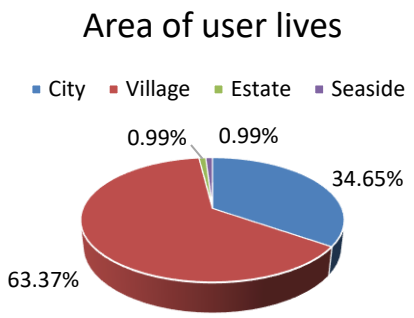


Figure 2.3 Percentage of respondents by area of the user lives

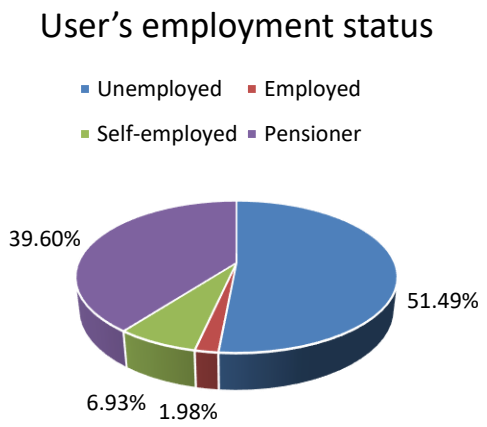


Figure 2.4 Percentage of respondents by user's employment status

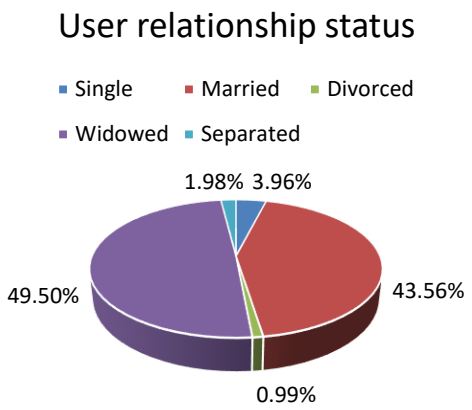


Figure 2.5 Percentage of respondents by user's relationship status

Figure 2.1 shows the percentage of respondent by gender. Based on this figure, 64% were female while another 36% were male. Figure 2.2 shows the percentage of walking stick users by their current age. According to this figure, the highest respondent with 39% of the total users aged between 70 to 79 years old while the second highest with 28% aged between 80 to 89 years old followed by 22% aged between 60 to 69 years old and 11% age for 90 years old and above. Figure 2.3 shows the percentage of the respondent by area of the user lives. Based on this figure, many of the users live in a village (63%), followed by 35% of the users who live in a city.

Next, Figure 2.4 shows the classification of the users according to their employment status. Accordingly, most of them are unemployed (51%). Next, 40% of the users are categorized as pensioners. And lastly, Figure 2.5 shows the percentage of users' relationship status. 49% of the users are widowed. In contrast, 44% of users are married. Based on our survey, there is a probability that some walking stick users became widowed just recently, related to the users' employment status and because the users were mostly female.

2.3.2 General Overview

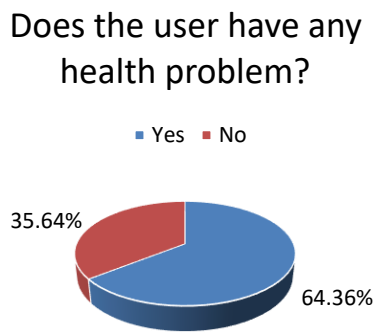


Figure 2.6 Percentage of respondents by user's health problems

Figure 2.6 shows the percentage of users whose having health problems. Based on this figure, most of the users were having health problems as shown by the result with 64% of the respondents while 36% of the users do not have any health problems. Secondly, Figure 2.7 shows details regarding respondents' health problems. Based on this figure, most of the users (22) have diabetes while 17 of the respondents have high blood pressure and 12 respondents have sprain on the knees followed by other health problems from the rest of the respondents.

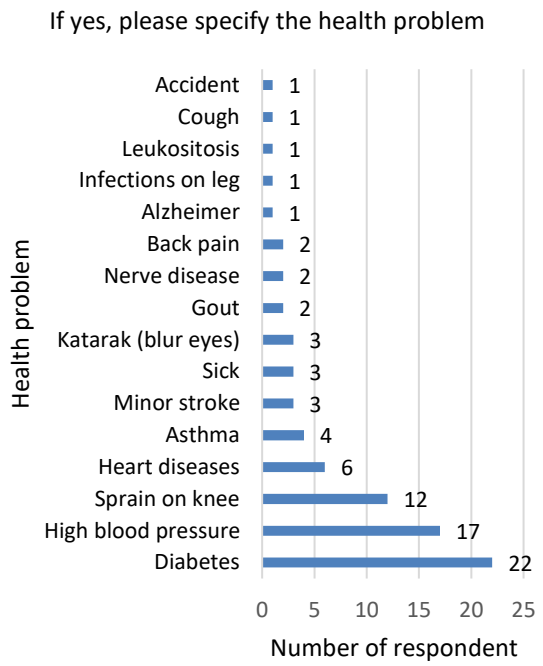


Figure 2.7 Number of respondents by user's specified health problems.

Furthermore, Figure 2.8 demonstrates reasons for the users to use walking sticks. Based on the figure, as expected, most of the users answered age-related mobility with 80.2%. This is related to the user's age which is old and has difficulties with their mobility. Based on this figure, respondents also chose "fall" and long-term medical conditions as the two main reasons for using walking sticks with 22.77% and 18.81%, respectively. This is followed by respondents with planned surgery, sports injury, diseases, and knee pain with percentages from 1.98% to 0.99%.

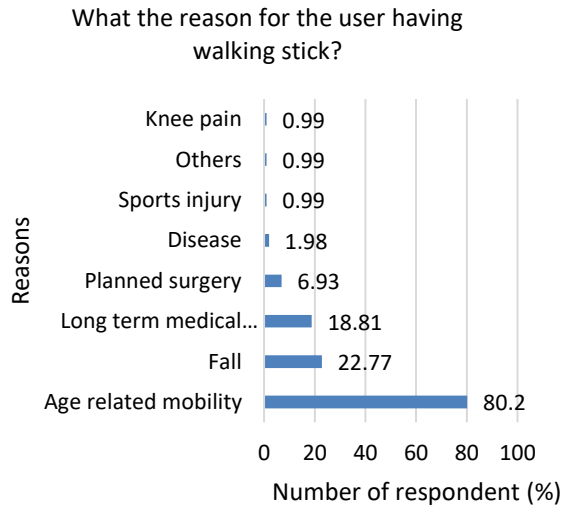


Figure 2.8 Percentage of respondents by reason for users having a walking stick.

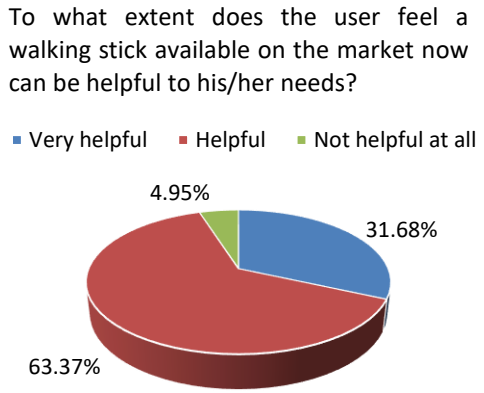


Figure 2.9 Percentage of respondents by user's expectation on the walking stick availability in the market

Moreover, Figure 2.9 shows the percentage of respondents by the user expectations on the walking stick availability in the market. Based on this figure, the majority of them (63%) answered that current products in the market are still helpful to them. Followed by that in second place is very helpful with 32% helpful and 5% answered it was not helpful at all. It can be deduced from this chart that the respondents do not have critical issues in getting a walking stick of their choice in the market.

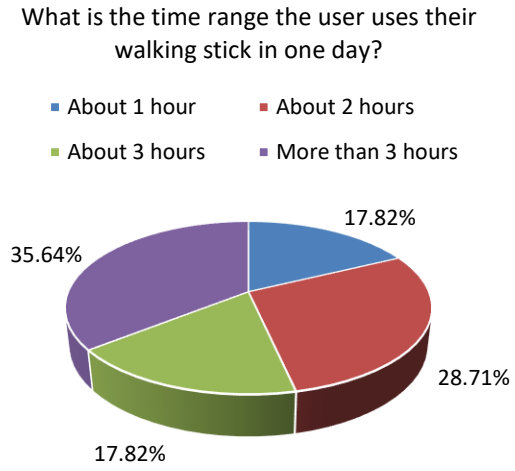


Figure 2.10 Percentage of respondents by the duration of usage in one day

Next, Figure 2.10 shows the percentage of respondents by their usage per day. Based on this pie chart, 35% of users used their walking stick for more than 3 hours. In the second place, 29% of the respondents indicate 2 hours of usage, followed by those who utilise the stick for 1 hour and 2 hours at 18% for both. As can be summarised from this figure, walking stick users used their walking sticks for a long time daily for their mobility, which relates to Figure 2.3 (the area where the users live). This is because most of the respondents live in a village, hence their radius of mobility from their home is wider.

Figure 2.11 illustrates the number of respondents by places where the walking stick is commonly used. Based on this figure, the majority of the users used it in the house with 64 persons, followed by around their home area with 52 persons. This is followed by going to grocery stores with 36 persons and also for leisure and to places of worship with 29 and 28 persons respectively. Based on the data presented in this figure, it can be deduced that most respondents had difficulties with their mobility and health problems since the majority of them use the walking stick while staying in their houses.

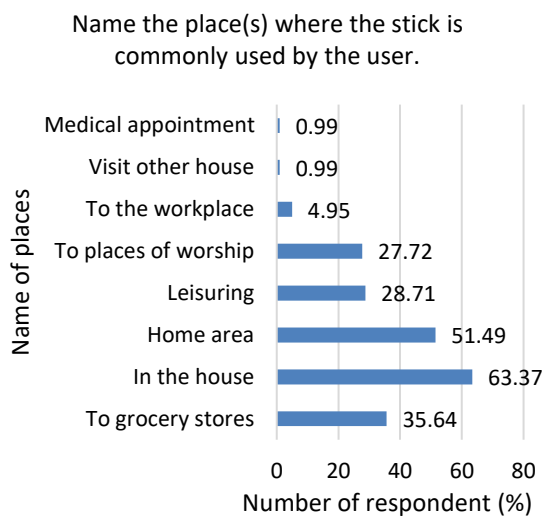


Figure 2.11 Number of respondents by places where the walking stick is commonly used by the user

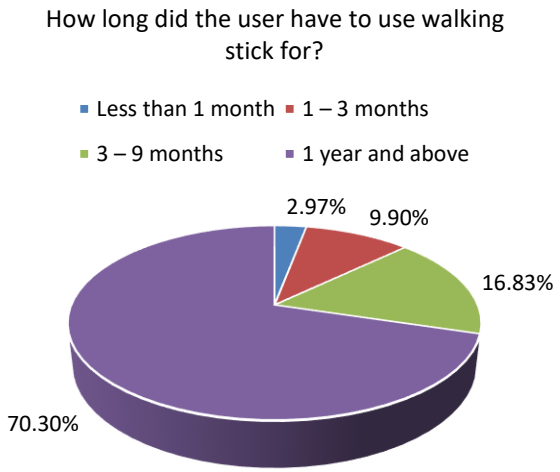


Figure 2.12 Percentage of respondents by the duration of usage

In addition, Figure 2.12 shows the percentage of respondents by how long users have been using the walking stick. Based on this pie chart, most of the respondents already used their walking sticks for more than 1 year. The second place is for 3 to 9 months with 17% of respondents. This is followed by 1 to 3 months and less than 1 month with 10% and 3% respectively. This chart shows that most of the users already used the walking stick for a long time

Finally, Figure 2.13 shows the number of respondents by user spending on the maintenance of walking sticks. Based on this bar chart, the majority of the respondents spend from RM50 to RM100 with 37 respondents followed by them is RM100 to RM150 with 26 respondents. 19 respondents indicated that they are willing to spend more than RM150 on a walking stick. These data show the common price that users were willing to spend on a walking stick.

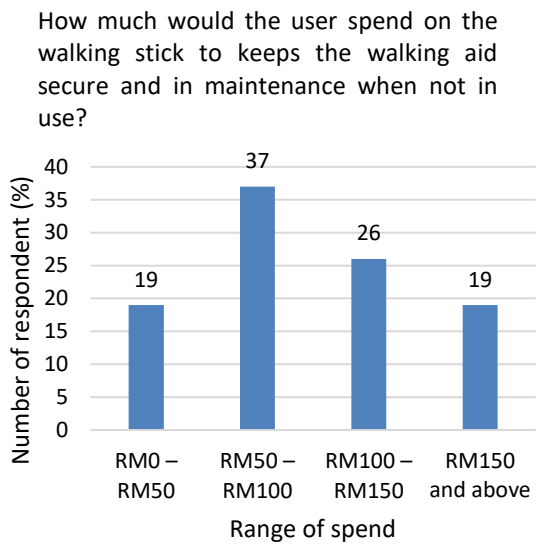


Figure 2.13 Number of respondents by user spending for the maintenance of walking stick

2.3.3 Problems

Figure 2.14 shows the feedback of respondents on the common problems faced during the users' use of their current walking stick. In the first statement, "their leg feels weak when walking" have the highest percentage with 39.6%. For the second statement, "they have to seat after walking for a while", the majority of respondents agreed which constitute 44.55% of the total respondents. Furthermore, 29.7% of the respondent strongly agree that this problem always occurs while using the walking stick. The third statement, "they have to hold on to something when walking without the walking cane", the highest percentage which is 37.62% was recorded for strongly agree.

Next, most of the respondents (40.59%) are not sure that the user would fall. Furthermore, the fifth statement, *"users have difficulties to get help for others when in an emergency",* is top voted with 32.67%. In the sixth statement, users have to get help from others when getting up from their seats, the highest percentage which is 33.66% is recorded as agreeing that users have to get help from others when getting up from their seats. Proceed to the next statement, most of the respondents (38.61%) agree that the user wobble. Furthermore, the eighth statement, users have been lost and confused on their way home, is top voted with 33.66% which is not sure that users have been lost and confused on their way home. This shows the walking stick has a good memory in memorising the road they usually use. Finally, the last statement is there are not a lot of facilities for senior citizens in their place. Strongly agreed recorded the highest percentage which consists of 32.67% of the total respondents.

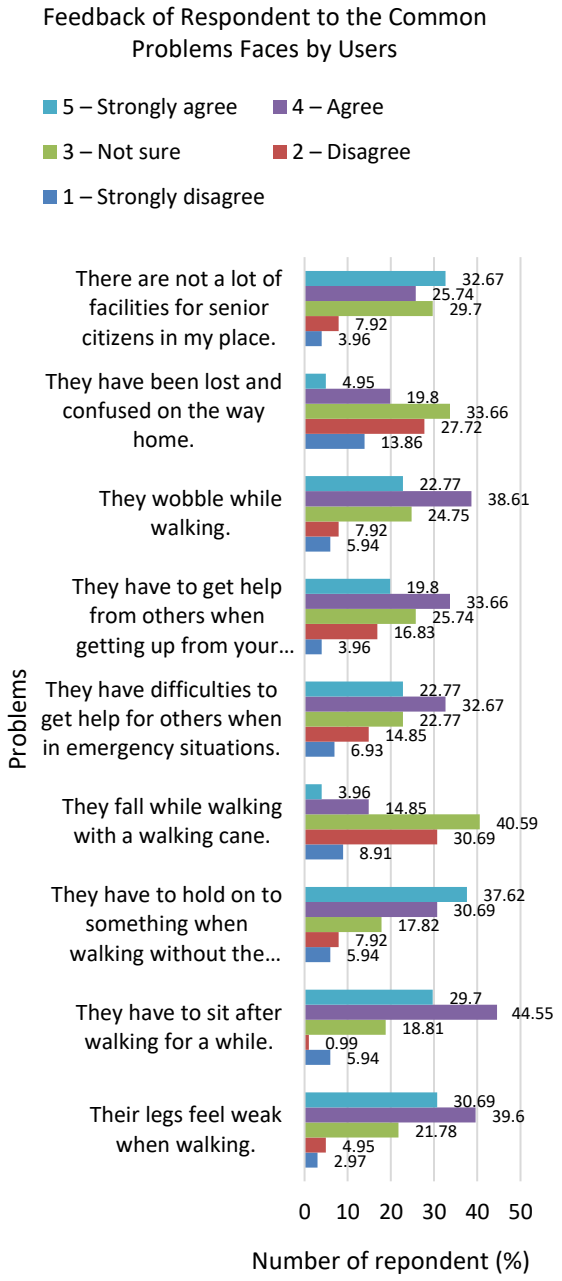


Figure 2.14 Feedback of respondents on the common problems faced by the user's walking routine

2.3.4 Possible Solutions for Users

Figure 2.15 shows the feedback on the solutions provided by the Smart Walking Stick. Based on this figure, most of the respondents (i.e., 50.5%) strongly agreed that the walking cane is equipped with an alarm in case of an emergency happens to them. For the second statement, the majority of the respondent, which is 54.46, strongly agree with a walking cane embedded with the GPS to track their location. The third statement is the walking cane has a stable element under the cane base, most of the respondents with 68.32% concur and totally agreed this

solution needed to be taken into consideration. Furthermore, the highest number of respondents with 45.54% strongly agreed that the walking cane has a knee bar for them to stand up from their seats easily. Finally, most of the respondents (i.e., 52.48%) strongly agreed that the walking cane has seat that can be folded and used easily.

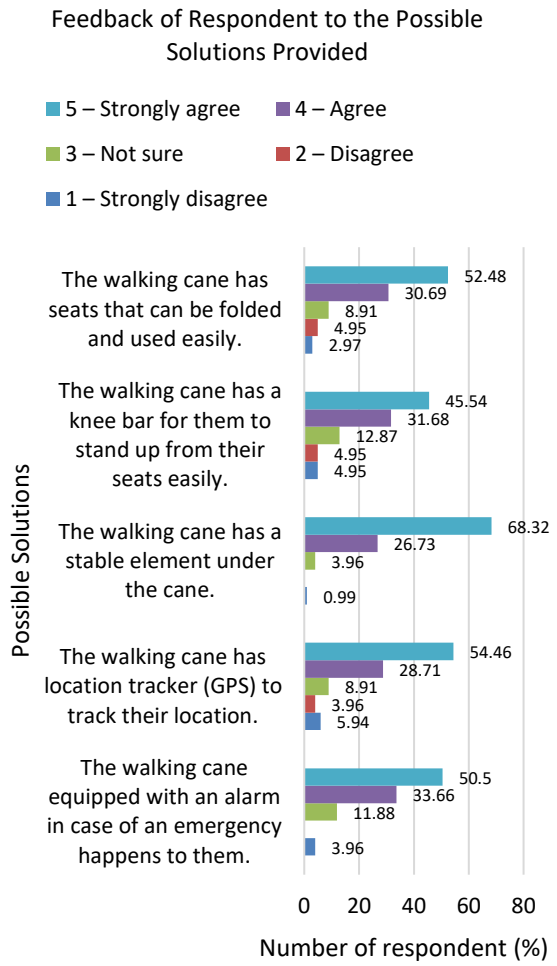


Figure 2.15 Feedback of respondents to the solution provided by a smart walking stick

3.0 Design Specification

3.1 Design Parameters Identification

Quality Function Deployment (QFD) is a systematic approach to defining customer needs or requirements and translating them into specific plans for producing products that meet those needs [17]. These stated and unstated customer needs or requirements are referred to as the "voice of the customer". There are three major steps are taken to implement QFD:

1. Prioritize both spoken and unspoken customer desires or needs.
2. Convert the identified requirements into technical terms and specifications.
3. Create and deliver a high-quality product or service by directing everyone's attention to customer satisfaction.

The QFD approach employs a matrix format that resembles a house, and thus it is also known as the "House of Quality" (HOQ). Then, the House of Quality (HOQ) is defined as a product planning matrix designed to show how customer requirements are directly related to the ways and methods that industries can use to meet those requirements [18].

House of Quality diagrams are created using technical and competitive benchmarking data and feature a design that resembles the outline of a house. Figure 3.1 shows the customer requirement employed in the HOQ for the smart walking stick for elderly people. Due to space constraints, the full-size HOQ is put in **Appendix A** (Figure A1). From the left side of this Figure A1, the customer requirements section lists the specific priority features on which the customer highly depends. On a scale of one to five, the numbers to the right represent their significance to the customer. Next, the Engineering requirement section demonstrates the engineering methods required to measure and execute production. At the base, the engineering requirements are detailed in specific measurements and the correlation matrix, also known as the HOQ's roof, represents the degree of dependence among the engineering characteristics.

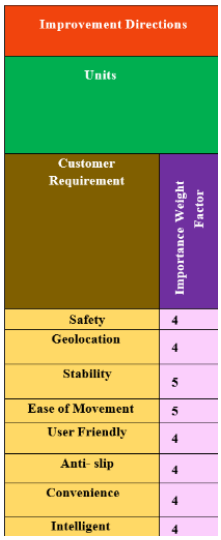


Figure 3.1 Customer requirement in the House of Quality for the smart walking stick

Based on Figure 3.1, the relative weights of the engineering characteristics are compared. The highest relative weight is 13.13% which is "Types of material properties," followed by 12.41% for "Sensor" and the lower is "Material Rigidity"

which is 5.48%. “Tracking Position”, “Cost”, and “Height” have the same relative weights which are 11.17%. From the figure, the most important requirement is “Type of Material Properties” and the least important requirement for this product is “Material Rigidity”.

Lastly, the important numbers and weights at the bottom represent the overall importance after assessing customer importance and engineering relationships. Before generating the HOQ for the smart walking stick, the importance weight factor, which is located next to the customer requirement, must first be calculated. Thus, Table 3.1 shows the calculations used as a reference for performing the importance weight factor in the house of quality (HOQ) to determine the product datum. From this table, there are five different factors listed under customer requirements. All these five factors have different importance weight factors, starting from 4 until 5.

Table 3.1 Calculation of the importance of weight factor

No	Customer Requirements	Product Specifications	Calculation	Importance Weight Factor
1	The walking stick equipped with an alarm in case of an emergency happens to them.	• Safety • Intelligent	1(0.04)+2(0)+3(0.12)+4(0.34)+5(0.51)=4.31	4
2	The walking stick has location tracker (GPS) to track their location.	• Geolocation	1(0.06)+2(0.04)+3(0.09)+4(0.29)+5(0.54)=4.27	4
3	The walking stick has a stable element under the stick.	• Stability • Ease of Movement	1(0.01)+2(0)+3(0.04)+4(0.27)+5(0.68)=4.61	5
4	The walking stick has a knee bar for them to stand up from their seats easily.	• Anti-slip • User Friendly	1(0.05)+2(0.05)+3(0.13)+4(0.32)+5(0.46)=4.12	4
5	The walking stick has seats that can be folded and use easily.	• User Friendly • Anti-slip • Convenience	1(0.03)+2(0.05)+3(0.09)+4(0.31)+5(0.52)=4.24	4

The product design specification (PDS) is the most important definition of what the product must provide. The PDS is a statement of the customer's expectations for the product. In some cases, the customer is external, whereas, in others (for example, product line extensions for own-brand products), the customer is internal.

3.2 Product Design Specification

Then, the PDS's objective is to provide a description and statement of a product's requirements, components, capability, or performance, and/or the service or work to be performed to create a product [19]. Table 3.2 shows PDS of smart walking stick for elderly people with descriptions.

Table 3.2 Product design specification of the smart walking stick for elderly people

Product Identification

a. **Product name:** Smart Walking Stick for Elderly People.

b. **Basic function:** To provide safety, comfort, and user friendly.

c. **Special features:**

- Anti-slip seat is ergonomically crafted for extra comfort.
- Alarm can be triggered automatically to attract attention in case of an emergency.
- Walking stick with knee bar to help up.
- Self-supporting base.

d. **Key performance target:**

- Able to detect user location when the accident happens.
- Able to send emergency messages to nearest emergency contacts.
- Powered by rechargeable batteries.

e. **Service environment:** Suitable in all environments and conditions.

f. **User training required:**

- Yes, because to ensure that users can control the walking stick properly based on user’s condition.
- User manual book provided to guide the user to operate the walking stick.

Key Project Deadlines

a. 2 semesters to complete the project.

Physical Description

a. **External dimensions:**

- Height adjusts: 81cm - 190cm.
- Seat dimensions: 20cm(width) x 24cm(height)

b. **Product weight:** 370g

c. **Support Maximum Load:** 120kg

d. **Material:** Aluminum alloy, rubber and, polycarbonate (PC)

Financial Requirements

a. **Pricing policy over life cycle:**

- Target manufacturing cost: RM300
- Estimated retail price: RM500.

b. **Warranty policy:**3-month complete warranty

c. **Expected financial on rate of return on investment:** To be determined (TBD).

d. **Level of capital investment required:** TBD.

Life Cycle Target

a. **Maintenance schedule:** Once a year for all electronic components.

b. **Reliability:** 3 years

c. **End of life strategy:** Certain parts of this product are recyclable and reusable:

- Parts made of aluminum alloy can be recycled.

Market identification

a. **Target:** Elderly people who need better balancing and support while walking.
b. **Initial launch:** UniMAP's IDP day.
c. **Anticipated market demand:** 50-100 units a year.
d. **Competing product:**

- Intelligent electronic walking stick
- Foldable walking stick

Walking stick with seat

Social, Political and Legal Requirements

a. Safety and environment regulation based on ISO 11334 is followed.
b. Standard and regulation of equipment.
c. Safety and product liability: Do not replace or adjust the system or component with other parts those different specifications. Refer to the nearest authorized service provider when one or more of the below-listed circumstances occur:

- If the product is dropped or its case is damaged.
- If the performance of the product has changed or need to be repaired.
- If an expected mechanical noise is coming from the product.

d. Intellectual property: Will investigate patent potential.

Manufacturing Specification

a. All the parts buy from different suppliers.
b. Supplier: To be decided.
c. All parts will assemble in the factory or workshop.

4.0 Concept Generation

4.1 Overview

Physical decomposition simplifies a device's complex problem or system while function decomposition creates structure. Additionally, block diagrams are used to show energy, material, and signal flow created using function structure. Combining these subsystems into a morphological chart will then help to create new concepts.

4.2 Design goal and Constraints

This project aims to help elderly people with weak legs by designing a walking stick with a fall sensor and alarm sound to alert passers-by while automatically sending a relative's GPS location. A knee bar and a seat were integrated into our design to help the elderly stand up and sit down safely. NodeMCU8266, which is a low-cost open source IoT platform was used in this project. Likewise, accelerometer sensors, which can detect vibration, shock, and uniform gravity was also employed. Our design also prioritises resource conservation. Rechargeable batteries were used as the main power source for this project since they use 23 times less non-renewable resources than disposables.

Rechargeable batteries store energy through a reversible chemical reaction, allowing USB charging after the battery is drained. It's also more powerful and efficient than regular alkaline batteries. Additionally, the cost of building a smart walking stick for elderly people is the project's main limitation since the majority of the respondents prefer a low-cost, albeit one with full features. For this smart system, price-based costing will be used to select materials and parts. This system requires some complex parts from stock. This is the product's toughest constraint.

4.3 Data, Information and Knowledge

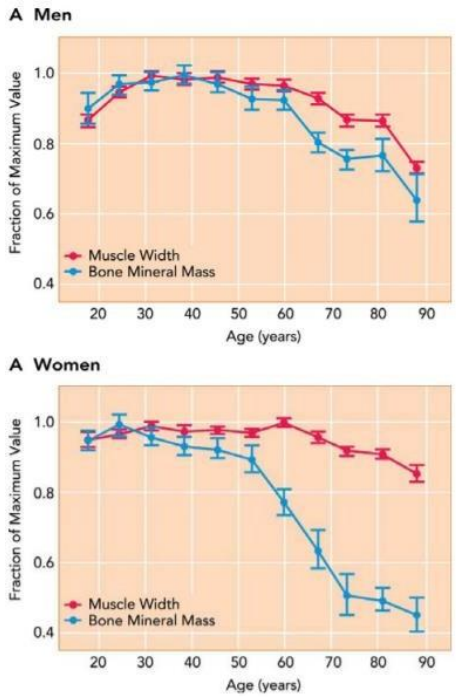


Figure 4.1 Aging-related changes in the bone mineral mass of the radius and muscle widthin the forearm in adult men and women [20].

The elderly start using a walking stick due to muscle and bone weakness, which causes them to lose balance, have postural disorders, and fall (Figure 4.1). Traditional walking sticks on the market are too simple for elderly people. Due to that, intelligent walking sticks are gaining popularity among the elderly. An anti-slip, comfortable grip handle, alarming, and added seat, sensor, and more functions can help elderly people. Caretakers or family members of elderly people are most concerned when they get lost, wander aimlessly, or are confused about where they are. For this, GPS tracking devices are a simple solution to many families and friends that have concerns about elderly people. Using a smartphone, family members can track the elderly using a GPS device.

This is helpful for elderly people who wander and get lost or who want to go out or walk alone. Another concern is the risk falling among the elderly. Fall detection devices can alert and quickly assist the elderly and allow them to call for help without pressing a button. These systems can be activated when the sensor detects a falling down movement. To design a product for the elderly, we must provide the support that can stabilise the elderly user while standing and walking. Additionally, the product must also be able to improve safety and security when nobody is with them. Not only that, but we must also consider the needs of our target audience. Finally, correct material selection prevents overbudgeting and lowers product prices.

4.4 Functional Decomposition

Functional decomposition (Figure 4.2) dissects a larger task into smaller tasks. During task decomposition, the team focuses on inputs and outputs and uses generic process descriptions. Functional decomposition helps the team identify parts. Notably, this project uses both function structure and physical.

4.4.1 Physical Decomposition

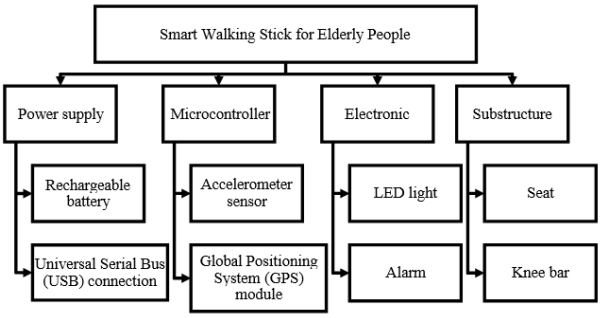


Figure 4.2 Physical decomposition of smart walking sticks for elderly people

4.4.2 Function Structure

A Function Structure Diagram (FSD) depicts the inputs and outputs of a product. These sub-functions are put into function blocks. Energy, material, or signal arrows represent interactions between function blocks. A black box model must be created before FSD. A Black Box Model includes product function, input and output flow. Figure 4.3 shows the black box model of a smart walking stick for elderly people while Figure 4.4 shows the function structure.

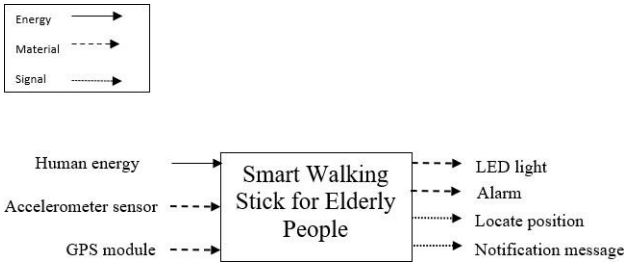


Figure 4.3 Black box of smart walking stick for elderly people

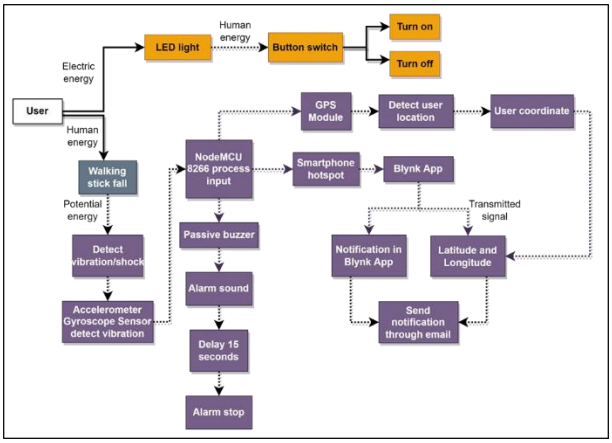
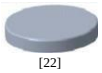


Figure 4.4 Function structure of smart walking stick for elderly people

4.5 Physic Of Design Ideas

Table 4.1 demonstrates a morphological chart that captures product functionality and explores alternative ways to achieve it visually. In a morphological chart, functions are on the left and concepts that can perform the functions are on the right. Hence, this chart yields a matrix of functions and mechanisms.

Table 4.1 Morphological chart of smart walking stick for elderly people

	Concept			
Function	**1**	**2**	**3**	**4**
Handle grip form	Derby handle  [21]	Crook handle  [21]	Ergonomic/ Contourhandle  [21]	T-Bar handle  [21]
Seat shape	Rectangle  [22]	Flat Square  [22]	Round  [22]	Half Round  [22]
Stable base	Three-Legged base  [23]	Three-Legged base  [23]	Three-Legged base  [23]	Three-Legged base  [23]
Knee bar	Foam knee bar [24]	Foam knee bar [24]	Foam knee bar [24]	Foam knee bar  [24]
Stick foot	Ferrule  [25]	6 support point  [26]	Type D  [27]	Hurryca ne  [28]
Safety lock	Rotate Lock  [29]	Twist Lock  [30]	Clasp Lock  [31]	Master Lock [32]
LED light	Clips LED light	Rotatable LED light  [34]	45° LED light  [35]	Adjustable LED light 

	 [33]			[36]
GPS module	NEO-6M  [37]	NEO-6M  [37]	Grove – GPSModule  [37]	Grove-GPS(Air530)  [37]
Alarm	PS1420 P02CT (70Db)  [38]	EDWARS SIGNALING (70dB)  [39]	KPEG232 (75dB)  [40]	GE BUZZER (80dB)  [41]

4.6 Physic of Design Ideas

Pressure is defined as the physicalforce exerted on an object. The pressure at the grip handle that is applied by the users when walking and sitting, can be expressed as:

$$Pressure, P = \frac{Force}{Area} = \frac{F}{A}$$

where force, F=mg and area, A= πr^2.
For the gravity, we can use as follows:

$$\text{Gravity, } g = 9.81 \text{ m}/s^2$$

To determine the normal stress when subjected to a large load at a particular point thatcauses to bend and become fatigued, the bending stress can be expressed as:

$$Bending\ stress, \sigma_b = \frac{My}{I}$$

where M is calculated bending moment, y is a vertical distance away from the neutral axis and I is the moment of inertia around the neutral axis. At the base, there is a frictional force at the stick feet. Friction is the force that resists motion when the surface of one object comes in contact with the surface of another. It can be expressed as:

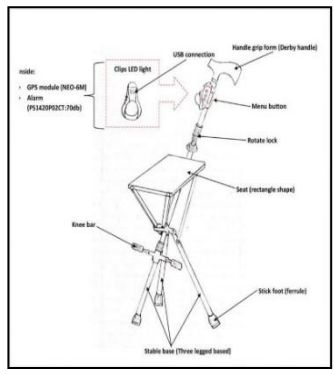
$$Frictional\ force, f = \mu N$$

where the coefficient of friction, $\mu = \frac{F}{L}$ and N is the normal force.

4.7 Concept Design

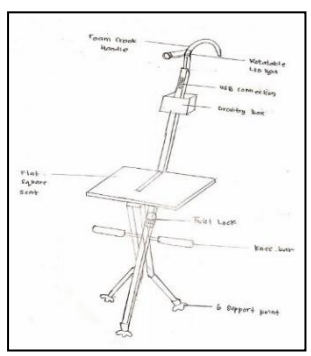
In concept 1 (Figure 4.5), a rechargeable battery powers this system. This system has a GPS and an alarm. The module uses a NEO-6M GPS chip. NEO-6M is a complete GPS module. The GPS receiver's 25 x 25 x 4 mm ceramic antenna improves satellite search. This system's main tracker is a GPS module. Next, alarm PS1420P02CT adds sound features. It has 2 small pins. This 70-decibel alarm can be triggered when a user falls to alert others of an emergency. LED light emits light when current flows through it, and the rotating lock serves as a safety device. To adjust the height of this walking stick, turn the rotating lock to the left to unlock and the right to lock. Foam kneebar, rectangle seat, derby handle, ferrule stick foot, and three-legged base are also included. Foam kneebar, rectangle seat, and derby handle provide anti-slip and extra comfort, while the ferrule stick foot and three-legged base provide stability.

Concept 2 (Figure 4.6) of the smart walking stick has a foam crook handle, plastic flat square seat, aluminum three-legged base, foam knee bar, and rubber six-point support. This system uses a rechargeable battery with a higher performance capacity and greater efficiency than regular batteries. The twist lock locks the height adjustment by rotating the stick 90°, and the LED light can be rotated for low and high beams. Next, GPS NEO-6M Modules and an Edward Signalling alarm are the smart walking stick's main components. GPS NEO-6M Modules' 2.5m GPS Horizontal Position Accuracy means more accurate coordination. The Edward Signalling alarm produces 70 decibels (dB), a safe sound that can be heard from 15 meters away in case of emergency.



Derby handle
Rectangle
Ferrule
Rotate lock
Clips LED light
GPS NEO-6M
PS1420P02CT (70dB)

Figure 4.5 Concept 1



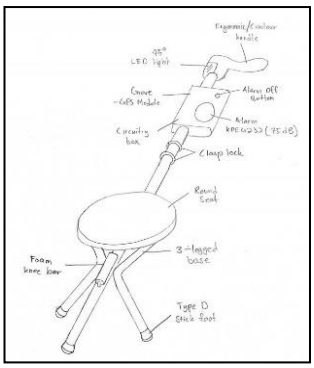
Crook handle
Flat square
6 support point
Twist lock
Rotatable LED light
GPS NEO-6M
Edward Signalling (70dB)

Figure 4.6 Concept 2

Concept 3 (Figure 4.7) smart walking sticks have ergonomic handles, flat round seats, three-legged bases, foam kneebars, and Type D stick foot rubber with 3 support points. This system's power comes from a rechargeable, high-performance battery. It powers the smart walking stick's electronic components more efficiently than regular batteries. In terms of convenience, the clasp lock locks the height adjustment by pulling out the clamp lock at the walking stick, while the LED light is static with a 45° angle that lights the user's path in a dark area. Next, Grove GPS Modules and an Alarm KPEG272 alarm are the smart walking stick's main components. Next, The Grove GPS Modules' 2.5m GPS Horizontal Position Accuracy produces more accurate coordination. For safety, the

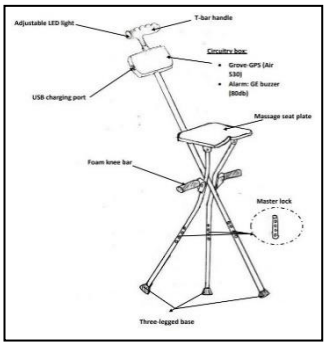
KPEG272 alarm produces 75 decibels (dB), which is a safe sound and can be heard from 15 meters away.

Grove Air530 (GPS) is a high-performance, multi-mode satellite positioning and navigation module that supports GPS, Beidou, Galileo, and more (Figure 4.8). This system's main tracker is a GPS module. Next, an intelligent GE buzzer adds sound features. This 80-decibel alarm can be triggered when a user falls to attract attention in an emergency. This system uses a rechargeable battery. LED light emits light when current flows through it in this system. This concept uses a height-adjustable master lock. The kneebar, hurrycane stick foot, seat, and T-Bar handle soft foam provide anti-slip and user comfort.



Ergonomic/Contour handle
Round
Type D
Clasp lock
45°-degree LED light
Grove – GPS module
KPEG232 (75dB)

Figure 4.7 Concept 3



T-bar Handle
Massage seat plate
Hurrycane
Master lock
Adjustable LED light
USB charging port
Grove – GPS (Air530)
GE buzzer (80dB)

Figure 4.8 Concept 4

4.8 Design Parameters and Constrain

4.8.1 Economical

Economical means avoiding waste. Economics is a social science that studies the production, distribution, and consumption of goods and services. Macroeconomics focuses on the aggregate economy, while microeconomics focuses on consumers and businesses. This project's economy is a customer goal. Theoretically, an economical product is one that best justifies its value to consumers. When something is sold for less than its perceived value, it loses value.

4.8.2 Sustainable Technology

Sustainable technology promotes economic and social development while preserving natural resources. These technologies reduce environmental risks and create a sustainable product. First, substitution defines technology sustainability. The technology shifts production toward biodegradable materials. It also uses renewable resources. Secondly, sustainable technology prevents deterioration, contamination, and other environmental impacts. Efficiency means the technology uses energy and resources efficiently. Our LED light is a sustainable technology in this project. Sustainable environmental technology could transform businesses and governments. Sustainable technology minimises social and environmental impacts, which boosts a company's bottom line and reputation. Sustainable technology reduces risk and improves project outcomes. Using renewable and biodegradable materials protects the ecosystem and reduces climate change.

5.0 Conceptual Design

5.1 Overview

This section discussed methods to make an appropriate decision on generated concepts. These methods include Weighted Decision Matrix (WDM) and Pugh Chart. Through these methods, the final decision can be made from all of the alternatives generated in the previous chapter.

5.2 Decision Making

In this decision-making phase, we had come out with 4 concepts for the final product, and we will finalize the concepts that are most suitable to meet the customer requirements. The concepts will be weighted by each engineering characteristic using decision-making tools and the Weighted Decision Matrix (WDM).

5.3 Weighted Decision Matrix (WDM)

A weighted decision matrix (WDM) is a method of evaluating competing concepts by ranking the design criteria with weighting factors and scoring the degree to which concept meets the criterion [42]. This criteria rating is integrated from the results of HOQ. To start with Weighted Decision Matrix, the following aspects are required:

- Criteria to be compared
- The defined relative importance of criteria in terms of weight
- Scoring the design alternative according to their performance

5.3.1 Objectives Tree

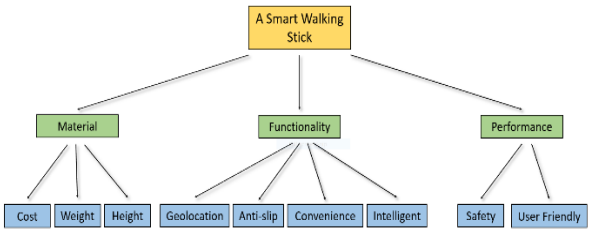


Figure 5.1 Objective tree of Weighted Decision Matrix

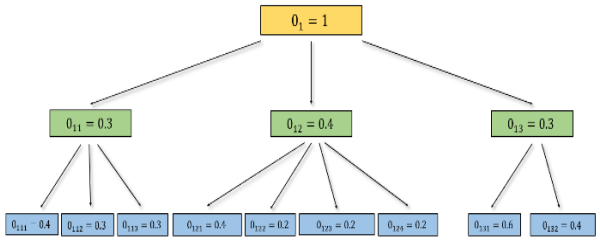


Figure 5.2 Probability of Weighted Decision Matrix

The formation of the objective tree is generated by separating the criteria into three categories which are material, performance, and functionality. The weight factors are assessed by using engineering judgment and in relation to the customer requirement weight matrix (Figures 5.1 and 5.2).

5.3.2 Scoring the Design Alternatives

To rank all the design alternatives, a 5-point scale as shown in Table 5.1 was used as a guide to score the probability of Weighted Decision Making (WDM) for A Smart Walking Stick. Due to space constraints, the completed Table of Weighted Decision Matrix is available in **Appendix A** (Table A1)

Table 5.1 Rating for Weighted Decision Matrix

Scale	Description
1	Very weak
2	Weak
3	Neutral
4	Good
5	Very good

5.4 Pugh Chart

The Pugh chart method (Tables 5.2 and 5.3) was implemented to determine the best concept to be used for the final design of the device. Pugh chart method was used in two stages as all concept generated is compared with a datum of an existing product in the market based on different criteria to determine which concept is better. To determine the best concept, each concept was compared relative to a datum or reference concept based on each criterion whether it is better than (+), poorer than (-), or about the same (S) as the reference concept. Thus, it is a relative comparison technique justified by the person who determines it.

In Table 5.2, the existing product (Intelligent electronic walking stick with T straight handle) had been chosen as the datum for the Pugh chart. Thus, the result shows that concept 4 obtained the highest total weighted score which is 5 while concept 1 and concept 2 received the lowest total weighted score which is -2 and -3. Next, in Table 5.3, concept 4 was set as the datum and compared with other alternative concepts. We can notice that the total weighted score of concept 1, concept 2 and concept 3 are negative values. This indicated that concept 4 is a better design after comparison. From this Pugh chart selection, the best result is verified with the previous WDM method. In conclusion, concept 4 is the final decision of our design product.

Table 5.2 Pugh Chart with existing product

Criteria	Intelligent electronic walking stick T straight handle	Concept			
		1	2	3	4
Cost		-	-	+	+
Weight		-	-	-	-
Height	**D**	S	S	S	S
Geolocation	**A**	+	+	+	+
Anti-slip	**T**	+	+	+	+
Convenience	**U**	-	-	+	+
Intelligent	**M**	-	-	+	+
Safety		S	S	S	S
User friendly		S	-	S	+
# of Pluses		2	2	5	6
# of Minuses		4	5	1	1
Total weighted score		-2	-3	4	5

Table 5.3 Pugh Chart within concepts

Criteria	Concept 4	Concept		
		1	2	3
Cost		-	-	+
Weight		S	S	S
Height	**D**	-	-	-
Geolocation	**A**	S	S	S
Anti-slip	**T**	S	S	S
Convenience	**U**	-	-	-
Intelligent	**M**	-	-	-
Safety		+	+	+
User friendly		S	-	S
# of Pluses		1	1	2
# of Minuses		4	5	3
Total weighted score		-3	-4	-1

5.5 Selected Design Concept

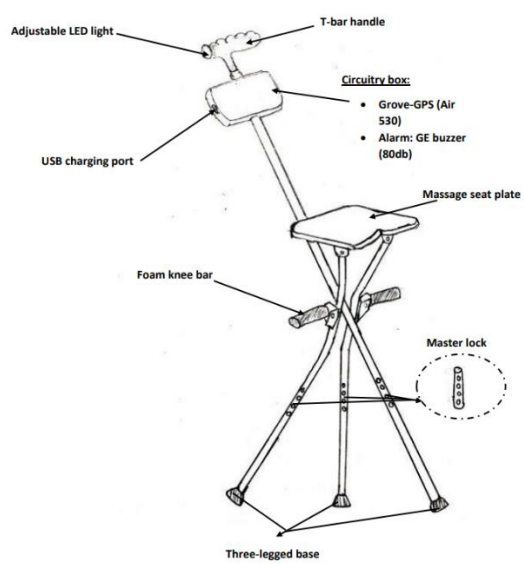


Figure 5.3 Selected design concept

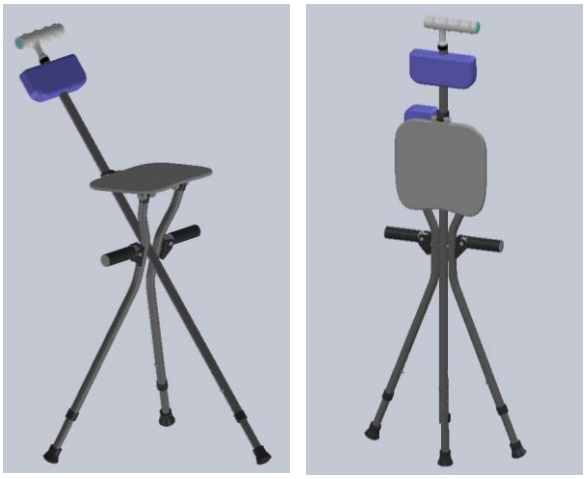


Figure 5.4 Isometric view of the selected design concept

In this project, conceptual design 4, as shown in Figures 5.3 and 5.4, was selected as the final design project based on complex decision-making using the Pugh chart and WDM. The criteria were obtained from the result of HOQ. This system consists of two main components which are GPS module and alarm. A Grove Air 530 (GPS) is a high-performance, highly integrated multi-mode satellite positioning and navigation module, supporting plenty of location systems, such as GPS. Thus, this GPS module was used as the main tracker in this system. Next, an intelligent GE buzzer was used to add sound features to this system. This alarm can produce sound at 80 decibels (dB) and can be triggered automatically when a user falls to attract attention in case of an emergency. A rechargeable battery was employed as power for this system. Then, adjustable LED light is a light source in this system that emits light when current flows through it. In addition, this concept used an adjustable master lock to set up a suitable height for the user. Lastly, the kneebar, hurrycane stick foot, seat and T-Bar handle soft foam are additional components in this concept that will provide an anti-slip feature that can give more comfort to the users.

6.0 Conclusion

A detailed market survey has been presented to highlight the needs of an improved walking stick that is not only functional, but also equipped with modern technologies. With more than 80% of respondents indicated age related mobility as the main reason for the reason of using a walking stick, this project aims to provide a comprehensive and innovative solution to improve the functionality of a standard walking stick to be used by the elderly and people with limited mobility.

Based on the extensive analysis conducted on the market survey, we came up with systematic design approaches to define customer's need by using House of Quality and also Product Design Specifications. Design concepts were then generated by outlining design goals and constraints with the use of Functional Decomposition, Weighted Decision Matrix and Pugh Chart. The selected design concept will be examined in detail in Part 2 of this paper, where product subsystem and architecture are examined. Additionally, parametric analysis in regard to engineering and safety aspects of the prototype will also be highlighted and discussed.

ACKNOWLEDGMENTS

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APPENDIX A

Legend	
Strong Relationship	9
Medium Relationship	3
Weak Relationship	1
Positive Correlation	+
Negative Correlation	-
Objective is Minimize	↓
Objective is Maximize	↑
Objective is Hit Target	N/A

Improvement Directions		↑	↑	N/A	↓	N/A	↑	↑	↑	↓	↑			
Units		m	m	cm	kg	cm	MPa	MPa/m	MPa	RM	Units			
		Engineering Characteristics										**Customer Competitive Assessment**		
Customer Requirement	**Importance Weight Factor**	Accuracy in Giving Information	Tracking Position	Size	Weight	Height	Material Rigidity	Material Toughness	Types of Material Properties	Cost	Sensor	Smart Walking Stick	Foldable Crutch Cane Walking Stick Seat Stool Chair	Intelligent Electronic Walking Stick
Safety	4	3	9				3	3	9	9	9	5	1	3
Geolocation	4	9	9							9	9	5	1	1
Stability	5			9	9	9	1	9	3			5	4	4
Ease of Movement	5			3	9	3						5	3	5
User Friendly	4			3	3	3			1		3	5	3	5
Anti- slip	4								9			5	1	3
Convenience	4			3	1	9	9	9	9			5	5	1
Intelligent	4	3	9							9	9	5	1	5
Raw Scores (967)		60	108	84	106	108	53	93	127	108	120			
Relative Weight%		6.20	11.17	8.69	10.96	11.17	5.48	9.62	13.13	11.17	12.41			
Rank Order		7	3	6	4	3	9	5	1	3	2			

Figure A1 House of quality for smart walking stick

Table A1 Table of Weighted Decision Matrix

Design Criterion	Weight Factor	Units	Concept 1			Concept 2			Concept 3			Concept 4		
			Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Cost	0.12	RM	350	3	0.36	380	3	0.36	280	5	0.60	300	5	0.60
Weight	0.09	Kg	0.8	4	0.36	0.8	4	0.36	0.8	4	0.36	0.8	4	0.36
Height	0.09	cm	80 - 90	4	0.36	70 - 80	3	0.27	80 - 90	4	0.36	75 - 85	4	0.36
Geolocation	0.16	Module	Good	3	0.48	Good	3	0.48	Excellent	4	0.64	Excellent	4	0.64
Anti-slip	0.08	Experience	Good	4	0.32	Good	4	0.32	Good	4	0.32	Good	4	0.32
Convenience	0.08	Experience	Good	3	0.24	Good	2	0.16	Good	4	0.32	Excellent	5	0.40
Intelligent	0.08	dB	70	4	0.32	70	4	0.32	75	5	0.40	80	5	0.40
Safety	0.18	Experience	Good	4	0.72	Good	4	0.72	Good	4	0.72	Good	4	0.72
User friendly	0.12	Unit	20	3	0.36	20	3	0.36	20	3	0.36	20	3	0.36
					3.52			3.35			4.08			4.16