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School of Engineering

PRJ 60403
Engineering Design and Innovation

Final Report of

BEEpsweep
Multi-functional Detachable Autonomous Cleaning Robots

Project Supervisor

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CONTENT

1.0 Introduction

1.1 Challenges

Generally, cleaning work such as sweeping, mopping and window cleaning require a lot of labour. This tedious and tiring cleaning work is usually carried out by adults. Therefore, ever since the 1860s, a variety of vacuum cleaners were introduced to make cleaning more efficient and productive. However, it is still tiring to move around these bulky cleaning devices and the wires do get tangled at times which causes cleaning to be inappropriate for young children to do. The first robotic vacuum cleaner was introduced in 1996 by a company known as Electrolux [1]. This automatic robotic vacuum cleaner is able to move by itself to perform its function. It did tackle the issue of tangled wires and energy-consuming cleaning work. However, it is still not productive enough for the current generation because other cleaning functions such as mopping and sweeping have to be done as well in order for the place to be fully clean.

Moreover, assigning household chores to children has always been a major concern for parents. Albeit their intentions of training and building up a sense of responsibility in their children as well as encouraging family unity, it is admittedly unsafe to entrust a child to do household chores by him or herself.

Therefore, in this module project, we aim to combine two features (vacuum cleaning and mopping) into one cleaning system where two devices operate individually. One device (runner as we call it) does the mopping while the other vacuum cleans. In our design, the device has two working modes which are autonomous and manual.

Our goal is to make household chores less tedious, safe and more fun so that even children can take part in cleaning duties. To achieve this, we created a user interface with touch buttons as shown in Figure 1 for the user to control the runners. This can enhance the interest in children to do the cleaning work, since they can control the runners as if they are playing with remote controlled toy cars.

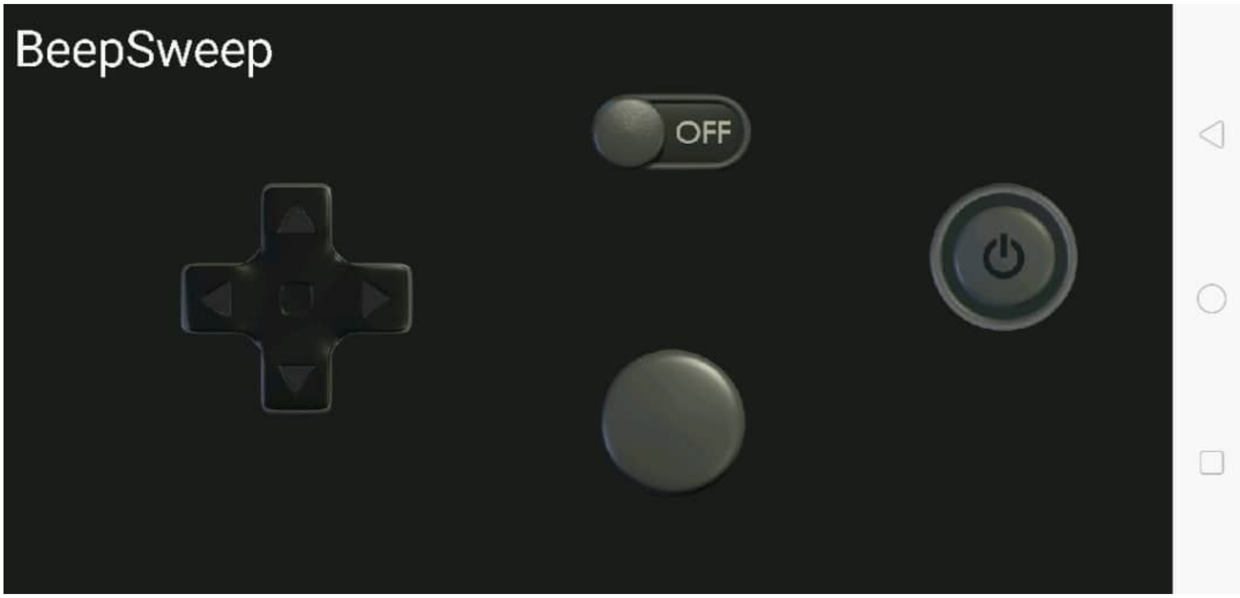

Figure 1 User Interface of runner in manual mode

Besides, we added an additional feature which is metal detector. The metal detector is installed to the vacuum cleaner. When the metal detector is turned on, it will notify the user when important items are sucked up. This can help us to track missing items such as jewellery.

1.2 Business Value

Cleaning is conventionally done manually and can be a tedious and time-consuming process. In this project, our goal is to overcome the challenge of easing the burden of cleaning work, make cleaning more fun so that children can take part too, and to track lost valuables. Therefore, we came up with a design of multi-functional autonomous cleaning robots that could reduce manual labor and instead increase work productivity by optimizing cleaning time within the budget of RM200. The criterias of the proposed solution to this challenge are as listed below:

1. Reduces manpower and effort
2. Multiple cleaning functions done at the same time
3. Save cost by reducing electricity bills and labour cost such as maid
4. Autonomous and wireless

Business Value Calculation

Based on the research (references [2] and [3]) done in our project proposal, the opportunities for business value gain of BEEpsweep include burden rate and headcount management. Since BEEpsweep can be used not only in households but institutions as well, the calculations (for detailed calculations, do refer to project proposal) are based on a rough estimate of an area of 3,000 square feet which covers the area of the second level of our university campus. In terms of burden rate, the labour cost for workers (includes salary, meal, accommodation and transport allowance) sums up to RM 1 438 560 for the traditional cleaning method and none for BEEpsweep. The major contrast in burden rate between both products can be based on the concept of headcount management which involves headcount reduction and headcount productivity. Headcount reduction is a process where the number of employees at a specific organization are reduced owing to a change in circumstances. In industries or institutions, the number of cleaning staff will significantly reduce with the introduction of an autonomous product like BEEpsweep. In households, the number of maids/workers required will decreased to little or none at all. It also increases both user and staff productivity alike as they have time to tend to other priorities. The estimated costs of equipments and electricity necessary for the traditional method of cleaning in institutions and industries are RM 355 702.60. Since BEEpsweep is multifunctional, organisations can cut down on bulky and expensive cleaning devices. With BEEpsweep, equipment and electricity costs sum up to RM 270 646.05. The equipment cost of BEEpsweep is the approximate manufacturing cost of a scaled up version of BEEpsweep that has been refined in the future. Overall, the cost of using BEEpsweep (**RM 270 646.05**) is much lesser compared to the cost of the traditional cleaning method (**RM 1 794 262.60**). The business value is **RM 1 523 616.55** per year while the return of investment is approximately 7 days.

Table 1 Comparison in Cost

	Traditional Cleaning	**BEEpsweep**
Labour Cost	RM 1 438 560	-
Electricity Bills	RM 123 022.60	RM 240 646.05
Cost of Equipments	RM 232 680	RM 30 000
TOTAL COST	**RM 1 794 262.60**	**RM 270 646.05**

Business Value = Total cost of old design - Total cost of new design
= RM 1 794 262.60 - RM 270 646.05
= RM 1 523 616.55 / year

Return of investment = $\frac{Investment}{Business\ Value}$
= $\frac{RM\ 30\ 000}{RM\ 1\ 523\ 616.55}$
= 0.019689×365 days
= 7.19 days ≃ **7 days**

2.0 Design Thinking Techniques

2.1 Understand

During this phase, we gathered information and asked all possible questions regarding the challenge. By doing this, we found the root causes which aids in designing a solution that addresses all the root causes the first time around or with as little changes needed.

In order to gain further insight regarding the issues that occur in different households, we interviewed a few individuals who have used manual vacuum cleaners before. A questionnaire was prepared beforehand. The answers from the interviewees were used as reference in our brainstorming. Through this, we could understand what the user really needs and the additional functions or features they want in a cleaning device. After the interviews, we noticed that all interviewees face a common problem which is the lack of time to clean their homes. Not only that, they tend to lose their valuables especially jewellery which always ends up inside the vacuum cleaner. Therefore, we decided to concentrate on building a cleaning device that shortens cleaning time and overcome the issue of losing small valuables.

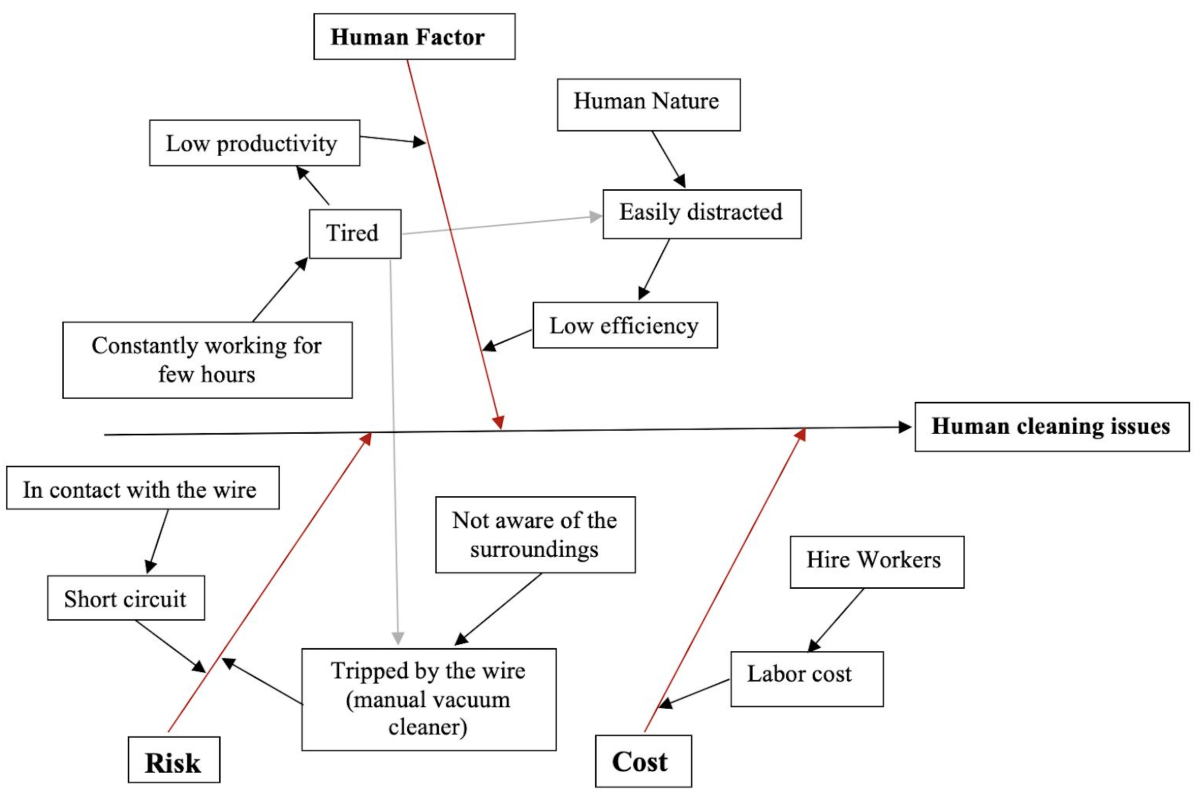

Figure 2 Ishikawa Diagram

The Ishikawa Diagram technique involves classifying the potential causes of an issue in order to pinpoint its root cause. This diagram also helps us to organize the causes systematically and act as a guide for us to create solutions. As from the Figure 2 above, the challenges and root causes are presented. The root causes are categorised into three; human factor, risk and cost. Firstly, there is a limit to the efficiency and productivity of a human. Since people nowadays are constantly busy with their studies and careers, they may find it physically exhausting to use manual cleaning devices. Humans also tend to get bored easily especially when doing something mundane like house chores. This reduces their efficiency since they may get distracted while cleaning.

In terms of cost, many people find it tedious to clean their homes and often hire maids or daily workers to do the job. The cost of this type of service is not cheap and will accumulate to a huge sum over a long period of time. To have an in-house maid, the homeowner will need to cover his/her food, accommodation, transport and other expenses Moreover, if the maid or worker gets injured during their service, the homeowner has to cover the expenses.

Next is the risks that may occur due to human factors or natural phenomena. For elderly users who may not be as alert as younger users, they are more at risk of obtaining injuries caused by tripping on wires or handling heavy equipments. In serious cases, these injuries may lead to hospitalisation or death. Touching wires with wet hands is also a habit that many of us may have. Doing this can potentially cause a short circuit and electrocution. Thus, manual cleaning devices require users to pay full attention when in operation.

2.2 Observe

Observing the challenge without the solution or observing the solution without a defined challenge are opportunities. The chance of coming up with an innovative solution becomes higher the more we have both observations. We could understand the needs of a user through practicing empathy and paying attention to what people said and did. By experiencing it for ourselves, we gained insight which leads to an inspiration.

During a brainstorming session, one of the team members brought up the concept of a honeycomb. Further brainstorming was done and eventually we had an idea of a dual cleaning system combining the vacuum cleaner and mopping systems. This will be discussed in the Ideate stage.

There was a day when a team member had the chance to help her family member on an earring hunt in their house. The earring ended up being inside the vacuum cleaner and this observation lead her to think of ways to improve cleaning devices. She wanted to make cleaning devices easier to use, consume less time and energy, and avoid sucking up valuable jewellery such as earrings and rings, using the technique of Six Thinking Hats. She was inspired and proposed an idea with the application of the honeycomb pattern. In addition to the dual cleaning system, she suggested a metal detector to be placed onto the vacuum cleaner to notify users when something important has been sucked up.

After another brainstorming session, the team tried to observe more on their surroundings and focus on how to avoid the same issue that occured. The Six Thinking Hats technique was introduced and used to aid us in our decision-making. Therefore, we were able to see the challenge from different angles and consider all perspectives when making a decision. Not only that, with the help of the 360 degree approach, we are able to push ourselves not to think repetitively but to think outside the box. Hence, this thinking technique assisted us with a more robust assessment on the challenge and solution.

There were a few matters that were studied after the observation was conducted. This included an issue that commonly occurs in almost every household which is valuables getting sucked into the vacuum cleaner without our knowledge. Secondly, users nowadays have fast paced lifestyles and care a lot about increasing their productivity. People are finding for ways to carry out menial tasks like daily cleaning chores without taking up much of their time and energy. Lastly, a dual cleaning system which combines vacuum cleaning and mopping are not common and not that technologically advanced in the current market. Lastly, users nowadays care a lot about increasing their productivity.

Table 2 Six Thinking Hats

Blue Hats	**How do we operate?** What is the issue? Time consuming and missing of small valuable items. What is the root cause? Current cleaning devices are not advance enough in terms of automation. There is no dual cleaning system that can work simultaneously causing waste of time. What is the solution? Installing metal detector to notify users when there is presence of metal. Programme both runner to work simultaneously.
Red Hats	**Do we like it emotionally?** The design is aesthetically pleasing and was inspired by the structure of the honeycomb. Easy to use with minimal steps required.
White Hats	**Why is this better compare to the current technology?** Affordable for all age groups and able to save time for students and office workers. As calculated in the first section, there is a potential BV for our automated robots.
Yellow Hats	**Why is this a good idea?** It is automated and 2-in-1 package that includes vacuum cleaner and mopping system.These automated robots with dual cleaning system that helps to vacuum and clean simultaneously will definitely get twice the results with half the efforts.
Black Hats	**Why is this a bad idea?** Not all the waste will be sucked up successfully especially metals. Short circuit will occur if the water spill out form the water tank.
Green Hats	**Think outside the box?** A metal detector is installed to the opening of the vacuum which serves to alert users of the presence of metal

2.3 Ideate

After we had gathered enough insight into the challenge and identified its root causes, we progressed to the Ideate stage. We had an inspiration for a concept in which we were confident would lead to an effective solution. In this phase, we utilised the trimming, random entry and challenge techniques.

Trimming

Using this technique, we broke down an existing product into its individual components and removed an important component without affecting its functionality. Firstly, basic vacuum cleaners usually have to be plugged into a power socket to function. We can eliminate the need for those wires/plugs by using rechargeable batteries that are inside the cleaning device itself. Besides, regular vacuum cleaners and mops have long hoses or handles that require the user to hold and control. We can do away with this component by 1) making an opening at the bottom end of the vacuum casing to suck up dirt, 2) attaching a self rotating mop at the base of moving device. To reduce the need for physical operation to the bare minimum, we can build a few autonomous devices capable of carrying out each of their own tasks.

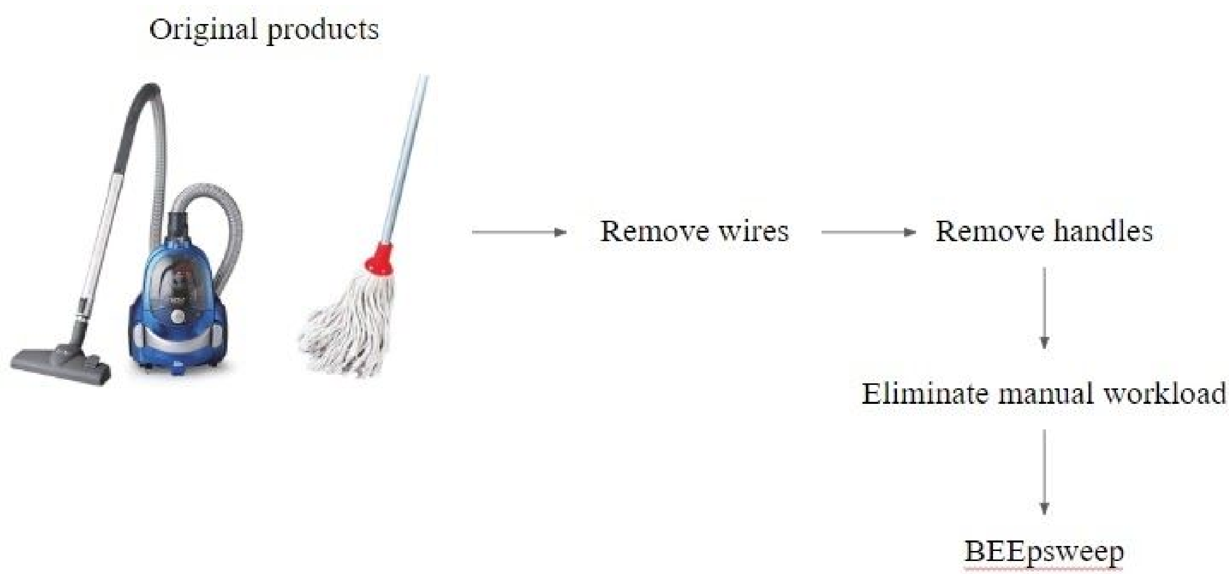

Figure 3 Trimming

Random Entry

This technique encourages us to use an unconnected input to open new lines of thinking. We chose a focus and a random object/picture/word, then listed its attributes and linked them back to the focus. In this case, the focus was how to improve the efficiency of conventional cleaning devices and the random picture we chose was of a beehive. Some of its attributes that can be linked back to the focus are its shape and the animal related to it.

We were inspired by the honeycomb pattern which is made up of many hexagons joined at all sides. We linked this to an integrated system composed of individual devices with matching sides that can assemble to become one. This can be done by constructing the components in a shape that has distinct sides with equal length and use magnets to enable them to attach/detach from each other.

Besides, we associated the beehive with a swarm of bees collecting pollen. Each bee collects pollen from a different flower than the rest at the same time. Similarly, we came up with a system consisting of several devices working all at once and at various areas. In this way, we can combine multiple cleaning functions into one coordinated system that increases efficiency. Bees also return to their beehive to stock up on the food they have collected. Likewise, we included a home base for the runners to return to when they are done with their tasks or when their batteries run low.

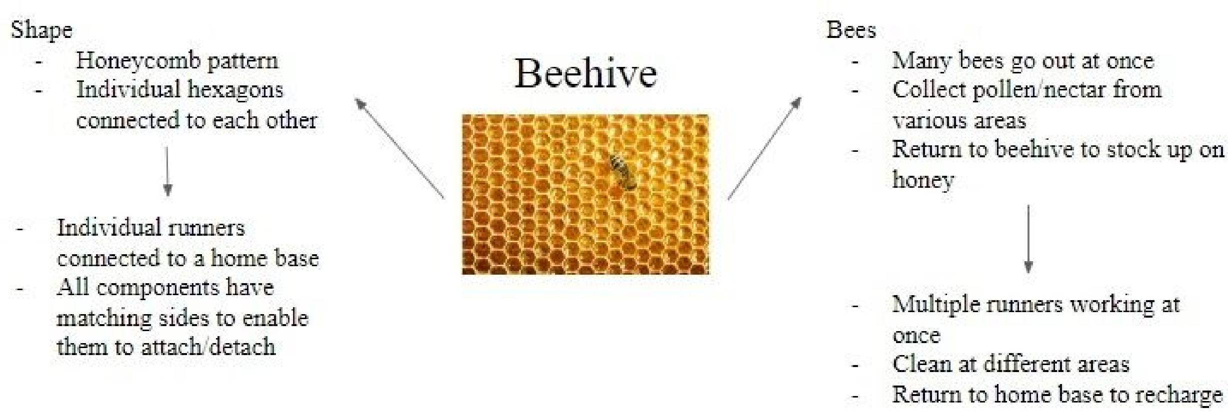

Figure 4 Random Entry

2.4 Prototype

Our prototype is a proof of our concept and allowed us to evaluate the concept and see how it would fit in from the user's perspective. It also allowed us to make early mistakes with little to no impact on cost. Our prototype was tested in scenarios similar to the ones during the final stages of the design phase. By doing this, we could identify the strengths and weaknesses of the prototype earlier and reduce the costs before final production. In this phase, we utilised mock-up and body storming technique.

Mock-Up

Since the control system involves an Arduino, a circuit prototype was constructed with minimal cost. Figure 5 displays the circuit prototype to test the cleaning and motion control. The prototype was made to look as close to its desired finish with the exception of using a breadboard to connect the circuit so that it will be easier to change any wires or components. In our proposed solution, the runners were supposed to return to their home on their own. Upon testing the circuit prototype however, we realised that this feature could not be made possible due to limitations of our knowledge in this advanced technology. Hence, we decided that the runners should change from automatic motion to manual motion with a click of a button before returning to their home.

We also constructed a simple version of the vacuum cleaning component to fully understand the mechanism and how to optimize its functionality. Using cheap and easily available materials such as a plastic bottle and a laptop cooling fan, we built a basic vacuum cleaner and conducted multiple tests and improvements until we got it to suck up bits of paper and dirt. The vacuum component was then drawn using SolidWorks referring to the shape and dimensions of the mockup and sent for 3D printing.

Body Storming

Body storming consists of role playing in multiple scenarios where there are many possible user responses to the design. This helps us to understand the user's experience by putting ourselves into their shoes. Figure 5 shows our proposed user interface in a Bluetooth control mobile application.

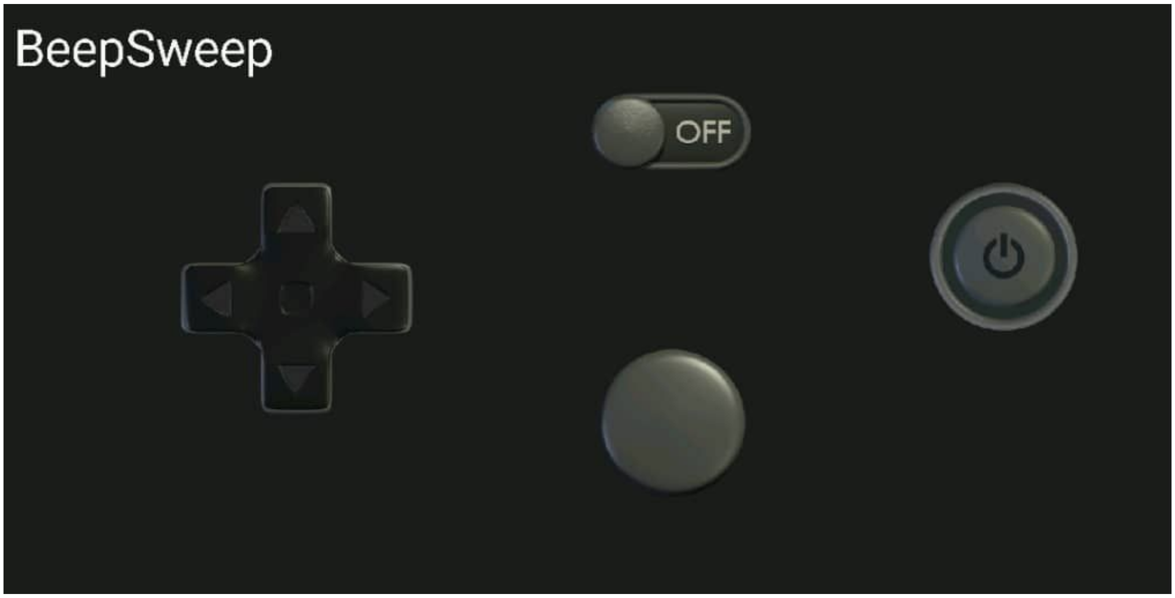

Figure 5 User Interface

In the application, we had already prepared a few buttons, each for a different purpose. There are two power buttons located at the right side of the screen; the "ON/OFF" slider button and the circular power button. The former is used to turn on and off the automatic movement function while the latter is used to turn on the manual movement function. On the left side of the screen, there is a set of buttons (similar to that of a game controller) to control the manual motion (forward, reverse, left, right). There is also a circular stop button at the bottom.

To ensure that our user interface was easy to operate, we recruited a few individuals who were unrelated to the project to test it out. They were provided an Android phone with the said application pre-installed. They were also given a paper with a set of instructions on how to use the product. During operation, the runner begins to automatically maneuver itself around the enclosed area upon clicking the slider button. When the battery is low or when the user is satisfied, the same slider button can be clicked again to stop the motion. After clicking the circular power button, the runner can be manually controlled to return to its home. By clicking the other set of buttons (aside from the power buttons), the runner will respond and move accordingly. The activity is completed once it reaches to its home.

Through body storming, we were able to obtain constructive feedback from new users. Some of the recommendations made by them were to label the buttons according to their functions and include simple instructions on the screen itself. This will ease their burden of having to memorise the steps or constantly referring to the user handbook.

3.0 Project Review

3.1 Cost

Table 3 Budget List

Bill of Material							
No.	Material	Description	Vendor	Unit Price (RM)	Quantity	Total (RM)	Project Total (RM)
1	Arduino UNO	-	Cytron	96.00	3	288.00	0
2	DC Motor	3V-6V	Cytron	1.50	5	7.50	0
3	Bluetooth Module	HC-05	Cytron	15.90	3	47.70	47.70
4	Neodymium Magnet	8mm x 3mm	Lazada	2.40	11	26.40	26.40
5	Perspex	0.5m x 0.5m	Lazada	50.00	1	50.00	0
6	Turbine Fan	Laptop cooling fan	Lazada	8.40	1	8.40	0
7	Micro Servo	SG90	Cytron	7.00	3	21.00	0
8	Lipo Battery	-	Cytron	12.50	2	15.00	0
9	Ultrasonic Sensor	HC-SR04	Cytron	3.20	4	12.80	12.80
10	Jumper Wires	Pack of 40 pc	Lazada	2.50	1	2.50	0
11	Motor Shield	-	Lazada	19.90	2	39.80	0
12	RC Wheel	65 x 26.5mm	Cytron	10.00	2	20.00	0
13	Filter Cloth	Mesh fabric	Lazada	3.50	1	3.50	0
14	Dust Container	5cm x 5cm x 2cm	Lazada	2.00	1	2.00	0
15	Circular Plate	Diameter 6cm	Lazada	0.60	3	1.80	0
16	Breadboard	-	Lazada	2.70	2	5.40	0
17	Microfibre Cloth	Diameter 7cm	Lazada	3.70	1	3.70	0
18	9V Battery	-	Lazada	2.00	1	2.00	0
19	IR Sensor	-	Lazada	8.90	2	17.80	17.80
Grand Total (RM)						575.30	104.70

Table 3 shows the bill of materials that was prepared during the planning stage. However, there were few changes made in the purchase of materials throughout the project.

Firstly, we planned to purchase 11 neodymium magnets from Lazada with a cost of RM 2.40 per unit. Initially, the neodymium magnet would be fixed to the base of the wall climbing runner. However, there was a change in the design of our project after having a consultation session with the project supervisor. The idea of building the wall climbing robot was eliminated and changed to a metal detector which would be integrated with the vacuum cleaning system. Hence, the team sourced copper wire for the metal detector from the school laboratory. In this case, the neodymium magnet was eliminated from the budget list and a total cost of RM 26.40 was reduced from the budget.

Besides, we planned to purchase 3 units of bluetooth modules from Cytron at RM 47.70 in total. Fortunately, the same type of bluetooth module was found from the electrical and electronics laboratory. Thus, only 2 units of bluetooth module were needed to be purchased and a cost of RM 15.90 was reduced from the budget.

Furthermore, instead of purchasing a turbine fan from Lazada, the team figured out that the fan could be constructed using the 3D printing machine provided in the laboratory. This was done by using the SolidWorks software to draw the turbine fan which would be sent to the 3D printing machine for printing. Besides, it is more suitable since the fan fits perfectly to the shaft of the DC motor and the vacuum cleaner casing. Therefore, a cost of RM 8.40 was reduced.

We also planned to purchase 2 IR sensors and 4 ultrasonic sensors from Lazada and Cytron with a total cost of RM 30.60. After modifying our design, we only required 6 ultrasonic sensors and no IR sensors. Since we were able to obtain all 6 ultrasonic sensors from the laboratory, we reduced RM 30.60 from the budget list.

All in all, a total amount of RM 72.90 was reduced from the grand total in the budget list since the budget decreases from RM 104.70 to RM 31.80. Hence, we successfully kept our budget under RM 200. There were no new components purchased throughout the building stage. This shows that by surveying the available materials in the laboratory, the team managed to cut down the actual cost of the project.

3.2 Project Timeline

Table 4 Gantt Chart

WBS Code	TASK	WEEK/DATE													
		01	02	03	04	05	06	07	08	09	10	11	12	13	14
						✔								✔	✔
1.0	**Understand and Observe**														
1.1	**Research**														
1.1.1	Identify challenge														
1.1.2	Gather information and statistics														
1.1.3	Conduct interviews/surveys														
1.2	**Plan**														
1.2.1	Analyse information obtained														
1.2.2	Identify root causes of challenge														
1.2.3	Identify solutions to challenge														
1.2.4	Calculate estimated BV of proposed solution														
2.0	**Ideate**														
2.1	**Detailed Drawing**														
2.1.1	Identify subsystems and components														
2.1.2	Sketch out design														
2.1.3	Provide specifications and label design														
3.0	**Prototype**														
3.1	**Budget Management**														
3.1.1	Compare prices and quality among vendors														
3.1.2	Purchase and obtain materials														
3.2	**Construction**														
3.2.1	**Motion System**														
3.2.1.1	Construct base and casing														
3.2.1.2	Construct whegs														
3.2.1.3	Assemble wheels/whegs and motors to base														
3.2.1.4	Coiling of copper wire														
3.2.2	**Cleaning System**														

3.2.2.1	Construct vacuum mechanism														
3.2.2.2	Construct mop mechanism														
3.2.2.3	Construct water storage, tubing and pump														
3.2.2.4	Construct window cleaning mechanism														
3.2.3	**Control System**														
3.2.3.1	Construct circuit for motion system														
3.2.3.2	Construct circuit for cleaning system														
3.2.3.3	Construct circuit for Bluetooth connection														
3.2.3.4	Programming for motion system														
3.2.3.5	Programming for cleaning system														
3.2.3.6	Programming for Bluetooth connection														
3.2.3.7	Programming for metal detecting system														
3.3	**Integration**														
3.3.1	Review and finalize design														
3.3.2	Integrate all systems														
3.4	**Testing**														
3.4.1	Test functionality														
3.4.2	Test reliability														
3.4.3	Test safety														
4.0	**Enhance/Improve**														
4.1	Minimize cost														
4.2	Increase efficiency														
4.3	Improve aesthetic														

KEY	Planned		Accomplished Planned Task		Additional Task		

Table 4 above shows the Gantt Chart that was planned during the planning stage showcasing the project timeline from week 1 to week 14.

For the research and planning stage, everything went accordingly to the project timeline. There were no obstacles faced yet in this stage. All the tasks were completed as planned in the Gantt Chart.

During the ideate stage, there was a 1 week delay that occured due to a change in the design of our product after having a consultation session with the project supervisor. The idea of building the wall climbing robot was eliminated. During that period of time, we went through another brainstorming session which required some time to properly plan the new design which was the metal detector that would be integrated with the vacuum cleaning system.

Fortunately, the project progress was brought back on track during the prototype stage. This is because most of the components was obtained from the laboratory. Therefore, there was no need for us to source the materials from vendors and compare prices. This saved us a lot of time.

During the construction stage, there was an additional task since there was a change in idea during the ideate stage. The coiling of copper wire task was added to replace the wheg assembly as the idea of building a wall climbing robot was eliminated.

As for the control system, the programming of bluetooth connection was delayed from week 11 to 12 due to some technical issue. Besides, there was also another additional task which was regarding the metal detecting system. This task was completed on time according to the project timeline.

The testing stage was a week behind schedule. The testing was expected to be completed during week 12 but was delayed to week 13. This was due to the inability of the bluetooth module to connect to the phone during the control system stage. Therefore, this task got delayed up until the testing stage since the runners needed to be connected and controlled using the phone.

Although there were delays that occurred and some additional tasks, the final improvements to our product was conducted as planned in week 13 and everything went considerably fine.

3.3 Project Task Distribution

Table 5 Linear Responsibility Chart

WBS Code	Element	Person In Charge				
		AY	JW	EG	MY	YS
1.0	**Understand and Observe**					
1.1	**Research**					
1.1.1	Identify challenge	1	1	1	1	1
1.1.2	Gather information and statistics	1	1	1	1	1
1.1.3	Conduct interviews/surveys			2	3	1
1.2	**Plan**					
1.2.1	Analyse information obtained	1	1	1	1	1
1.2.2	Identify root causes of challenge	3	1	3	3	2
1.2.3	Identify solutions to challenge	1	1		1	
1.2.4	Calculate estimated BV of proposed solution	1			3	3
2.0	**Ideate**					
2.1	**Detailed Drawing**					
2.1.1	Identify subsystems and components	1	1	1	1	1
2.1.2	Sketch out design		2	3	1	1
2.1.3	Provide specifications and label final design	2		3	1	2
3.0	**Prototype**					
3.1	**Budget Management**					
3.1.1	Compare prices and quality among vendors	1		2	3	2
3.1.2	Purchase and obtain materials	1	1	1	1	1
3.2	**Construction**					
3.2.1	**Motion System**					
3.2.1.1	Construct base and casing	3		1	3	
3.2.1.2	**Laser Cut the base**	**1**		**2**		
3.2.1.3	Construct whegs	1	2	2	1	3
3.2.1.4	Assemble wheels/whegs and motors to base	2		1		2

3.2.2	**Cleaning System**					
3.2.2.1	Construct vacuum mechanism	2	1			3
3.2.2.2	3D print vacuum components	1		2		
3.2.2.3	Construct mop mechanism			2	1	
3.2.2.4	Construct water storage, tubing and pump	3		2		1
3.2.2.5	Construct window cleaning mechanism	1	1		2	
3.2.3	**Control System**					
3.2.3.1	Construct circuit for motion system		1	2	2	3
3.2.3.2	Construct circuit for cleaning system	1		3		
3.2.3.3	Construct circuit for Bluetooth connection			1	2	
3.2.3.4	Programming for motion system		2			1
3.2.3.5	Programming for cleaning system	3	2			1
3.2.3.6	Programming for Bluetooth connection	2	1			3
3.3	**Integration**					
3.3.1	Review and finalize design	3	3	2	1	2
3.3.2	Integrate all systems	2	1	3	3	3
3.4	**Testing**					
3.4.1	Test functionality		1	2	3	
3.4.2	Test reliability	3		1		2
3.4.3	Test safety	1	3		1	1
4.0	**Enhance/Improve**					
4.1	Minimize cost	1	2		3	
4.2	Increase efficiency	1	1	2	2	3
4.3	Improve aesthetic	1		2		3

Legend: AY = Yip Winn Sheng Alwyn   1 = Primary Responsibility JW = Kuan Jun Wei   2 = Support/Work MY = Lim Min Yee   3 = Must be consulted EG = Eugene Gow Jun Yi YS = Wong Yi-San

The task distribution throughout the whole project was as according to Table 5. All team members performed their tasks as planned from the linear responsibility chart. However, there was an additional task which is highlighted at WBS code 3.2.1.2 and 3.2.2.2. These tasks are the 3D printing of the vacuum component which consists of the fan, upper and lower compartment. In addition, laser cutting was also used to shape the base of the vacuum cleaner to be as accurate as possible. Both of these tasks were done by AY (Alwyn Yip) and EG (Eugene Gow). This is because AY and EG were more familiar with executing the design of the vacuum cleaner after already producing an early prototype prior to 3D printing the parts. The only major difference is the construction of the window cleaner. During the early stages of the project, we decided to drop this feature due to time constraint and complexity of this mechanism. All in all, with the linear responsibility chart, we were able to fully understand our roles and main tasks of each member. There were minor changes such as switching of tasks during the construction stage due to the time needed to successfully complete each task.

3.4 Economic Viability and Environmental Sustainability

The Multi-functional Detachable Autonomous Cleaning Robots (BEEpsweep) is economically viable since the materials and components used to construct it are easily attainable and affordable. The whole vacuum cleaning device including the turbine fan was built by using the 3D printing machine that is provided in the lab. In this case, this 3D printing method replaces the manufacturing process used to construct the specific size of the vacuum cleaning device. Therefore, this reduces the cost of building this product since the cost of 3D printing is lower than the cost of manufacturing. The aim of the BEEpsweep is to reduce the cost of cleaning and at the same time increase the efficiency of cleaning. This helps to reduce the number of workers and thereby reduces the labour cost. During the planning stage, the business value was calculated to compare with the cost of traditional cleaning and an average of RM 1 523 716.55 could be saved per year.

The BEEpsweep is also environmentally sustainable as the whole vacuum cleaning device is built by the 3D printing machine. The raw material used in the 3D printing machine is PLA also known as the Polylactic Acid. PLA is a biodegradable thermoplastic that is made out of renewable sources making it an environmental friendly product. Since PLA is a biodegradable product, it can be decomposed by bacteria and thereby do not harm the environment when they are disposed as waste [6]. Besides that, PLA material have high strength which means that the durability rate of the vacuum cleaning device is high and this will be beneficial in a long run [7]. Hence, this could also reduce any excess wastes that will be disposed to the environment when it became faulty.

3.5 Risks Assessment

Table 6 Risk Assessment

Frequency of Category	Risk	
	Low Risk	**High risk**
1.If user is reckless	Wrong attachment of battery poles will lead to failure of the arduino and motor shield of the vacuum cleaner.	User might over refill the water in the water tank of the mopping cleaner. This might lead to failure of electronic components.
2.If user does not perform monthly maintenance	The dust accumulated in the storage tank will overflow and affect the inner mechanism of the vacuum cleaner.	The filter in the vacuum cleaner needs to be changed to prevent small particles from damaging the motor.

Colored Cells are the Risk Categories	Low Risk	Medium Risk	High Risk

Frequency of Scenario	Severity of Consequences		
	Low Severity	Medium Severity	High Severity
High Frequency	Medium	High	High
Medium Frequency	Low	Medium	High
Low Frequency	Low	Low	Medium

Figure Risk Assessment Matrix

The risk of BEEpsweep has been categorized into 2 separate columns as shown in Table 6. The risk are assessed based on the Risk Assessment Matrix which shows the severity of the risk from low risk to high risk. The first risk that we foresee is where the user uses the product recklessly. Every product comes with a proper guidebook on how to operate the device, so does BEEpsweep. The guidebook will guide the user on how to switch on and off the device by inserting the batteries at the right poles. If the user failed to follow the right steps, it may lead to the failure of the arduino and the motor shield of the cleaner. However, this risk is considered mild as the arduino and motor shield can easily be replaced. The probability of this incident to occur is very unlikely as user should be able to identify the right poles as shown in the guidebook. Hence , this risk falls under the low risk category.

Besides, the mopping cleaner contains a water tank in order to carry out the mopping function. The water tank can only be filled up to an appropriate level in order to avoid overflowing. However, when the user overfill the water tank, the electronics and circuit boards might be damaged and there may even cause a short circuit. This probability of this incident is very likely hence this risk is considered as high risk.

The second risk that we foresee is when the user does not perform monthly maintenance. As for the vacuum cleaner, dust will be accumulated overtime in the storage tank and will overflow once it is filled to the brim. If the storage tank is not cleared, it may affect the efficiency of the vacuum cleaner as the cleaner is unable to suck in more dust. In severe condition, it may even affect inner mechanism of the cleaner. In addition, the vacuum cleaner also contains a filter panel which acts as a barrier to prevent small particles from entering the motor of the cleaner. However if the filter panel is not changed regularly, small particles will be able to enter the electronic compartments of the vacuum and may damage the motor which will ultimately lead to the failure of the whole cleaner. Hence, this risk falls under the high risk as it is very likely to happen.

3.6 Flaws and Improvements

The manual and automatic function of BEEpsweep is controlled by any device that has Bluetooth connectivity. This connection can only be transmitted with a standard range of approximately 100 meters or 328 feet away. This makes BEEpsweep unable to function when the user is away from this device.

In addition, BEEpsweep is run by a 7.4 rechargeable lipo battery which could only last for approximately 2 hours.This is because of the multifunction of the cleaner which includes a metal detector, motors and vacuum fan which all operates at the same time. All this features takes up most of the capacity of the battery. Hence, the cleaner has to be recharged every 2 hours in order to fully function again which will cause the delay in the cleaning process.

There are a few improvements that can be done to further elevate this cleaner to its maximum potential. First and foremost, BEEpsweep should have a wireless connection which enables the user to be connected to the cleaner at all times. This will be more convenient as the user can control the movement of the cleaner without being present physically. In addition, BEEpsweep should have a power saving function which enables the cleaner to save battery usage when it is not in use. Batteries of larger capacity or hydrogen fuel cell can also be used as replacement to have a longer and continuous supply of electricity. Besides, the aesthetic of BEEpsweep can be improved by reducing its size and constructing an outer casing with a sleek design. Lastly, BEEpsweep can be further expanded to have more versions with various functions to cater to every need of a household or an industry. In the future, the BEEpsweep concept will be capable of doing almost everything with further refinements.

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