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Design and Development of Stabiliser for Electric Unicycle

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Abstract – *This paper presents the research on design improvement of a self-balanced electric unicycle model which is available in the market. The improvement work is focused on the stability and the ease-of-use of the electric unicycle. The selected method for improvement is the automatic support wheels. In terms of stability, the additional two small wheels at both sides of the unicycle increase the contact area perpendicular to the unicycle motion and thus reduce the tendency of toppling to the lateral direction. The additional wheels can be expanded and retracted by using a control system where it is suggested that the wheels fold out at riding speed lower than 10km/h and fold in at riding speed higher than 10km/h. These retractable wheels overcome the difficulty of travel initiation and stopping of the original unicycle. The experiment shows that by using the prototype, the users experience better stability when using the unicycle with retractable wheels compare to when using the original unicycle.*

Keywords: Electric unicycle, self-balanced, gyroscope, zero-emission, Arduino

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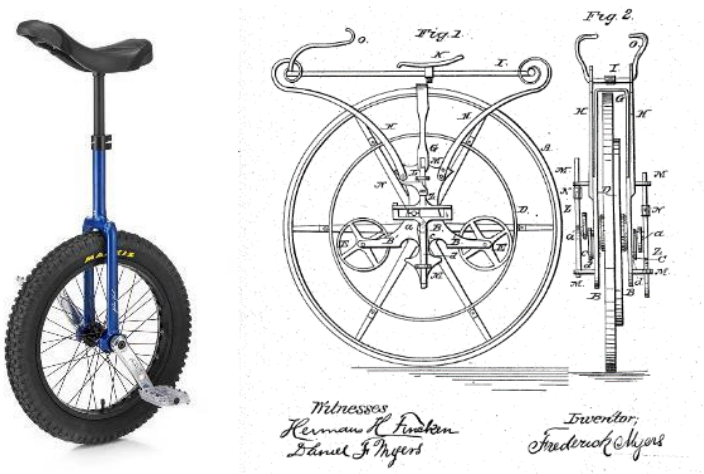
1.0 INTRODUCTION

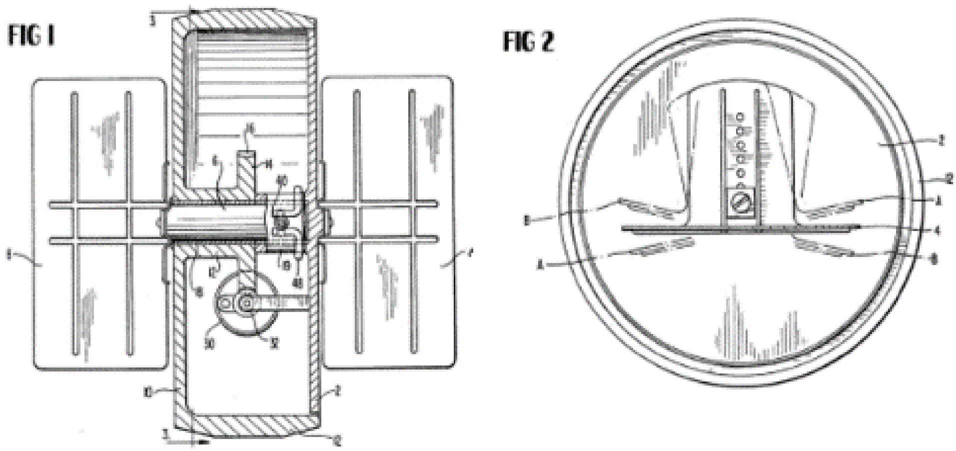
A unicycle is a vehicle with only one wheel that touches the ground. The conventional unicycle, as shown in Figure 1, is rarely used for transportation due to the difficulty of learning to ride and using it. The user needs to balance both the right-left and front-back sides to be able to ride the vehicle. Usually, the unicycle is used for extreme sport, hobby, and performance. The first patented unicycle was designed by Fredrick Myers in 1869, and it is called Velocipedes (Myers, 1869), as shown in Figure 1.



(a) (b)

Figure 1: (a) Conventional unicycle, (b) First patented unicycle

Throughout time, unicycle design has been improved in terms of stability and ease-of-use to allow the vehicle to be used as convenient transportation. Therefore, in this modern era of technology, an electric unicycle was invented to achieve the mentioned purpose. The electric unicycle has automatic movement features controlled by the sensors and electronic systems inside it. The first electric unicycle ever patented is by Charles L. Gabriel (Gabriel, 1977), as shown in Figure 2. This invention consists of a body structure and two fixed pedals attached to the body for the rider to stand. The driving force is provided by a rotatable ground engaging unit inside the hollow body structure. This unicycle operates by tilting the pedals forward or backward to control the speed and direction of rotation of the rotatable unit. This feature is also called a self-balancing feature, where the unicycle is prevented from tilting in the forward and backward movement, and hence removing half of the difficulty of riding the conventional unicycle. Based on the electric unicycle patent, many upgraded designs of electric unicycles are made to further improve usability as appropriate transportation.



(a) (b)

Figure 2: Motorized Unicycle Wheel; (a) Top view, (b) Side view (Gabriel, 1977)

The current available electric unicycle has several advantages and disadvantages. In terms of the environmental aspect, the source of energy is electricity from the battery, which means there is no emission of greenhouse gases like in-vehicle powered by a combustion engine (Environmental Safety Center, 1998; Perujo, 2011; Khan, 2016). In terms of energy, since the vehicle is light and can be far lighter than human weight, the energy consumption to operate this vehicle is low (Malmgrem, 2016; Yazid et al., 2011). In terms of health, riding the unicycle can correct body posture since it trains the rider to stand upright to maintain the right-left balance (AirDawgVibes, 2015).

The main drawback of the electric unicycle is the right-left instability while riding the unicycle due to the one-wheel feature. This issue needs to be solved to increase the usability of this vehicle significantly. Another important aspect of electric unicycle design is the suitability of this vehicle as a transit between home, public transports, and workplace. The unicycle should be compact and light-weighted to allow it to be carried easily while transiting. In this work, a new design of electric unicycle with a focus on stability and usability was produced to overcome the problem.

This study involves the processes of designing, simulating, fabricating, and testing to achieve the desired objectives. The process of designing and simulating requires the usage of licensed software that is available in the faculty laboratory. The required software is CATIA V5 and ANSYS for designing and simulating, respectively. The fabricating process involves material selection and requires some machining processes. The fabrication process is compulsory to modify the available electric unicycle and incorporate it with the new mechanism to increase the stability of the electric unicycle. The testing process is conducted after the fabricating process is completed to test whether the modified electric unicycle is working fine or otherwise.

2.0 PRODUCT INVESTIGATION

Product investigation is carried out to identify the available designs of the electric unicycle and other related products in the market. Afterward, the information was used to generate ideas of stabilised electric unicycle design.

2.1 Types of Electric Unicycle

There are various types of electric unicycle in the market nowadays. The following are the most common electric unicycle designs found in the market:

2.1.1 One-wheeled

This is the most common type of electric unicycle. It consists of only one tire, foldable pedals, and usually is compact in size and light in weight. This type of unicycle has its aesthetic value in terms of its compact size, sporty looks, usage flexibility and can be considered as an extreme sports vehicle. The main disadvantage of this unicycle is the difficulty in gaining right-left balance while riding it. It requires a lot of time and effort to learn how to ride the unicycle. Figure 3 shows the typical one-wheeled electric unicycle.

2.1.2 Double-wheeled

The double-wheeled unicycle is a design that significantly solves the stability issue of the one-wheeled unicycle. This unicycle can stand by itself when switched on since the right, and left wheels support the structure from toppling to the sides. However, the cons of this unicycle are it has a slightly bigger size and weight compared to a one-wheeled unicycle. The cons are due to the additional wheel in the vehicle. Figure 4 shows one example of a double-wheeled unicycle.

Figure 3: InMotion V8 Electric Unicycle (InMotionWorld, n.d.)

Figure 4: Double-wheeled Electric Unicycle (GlobalSources, n.d.)

2.1.3 Handle and wide tire

In solving the stability issue, a unicycle which includes a handlebar and wide tire was produced. The handlebar helps the user to keep the balance while riding this unicycle. The handlebar also allows the rider to make a turn by twisting the handle. The wide tire helps to improve the stability of the unicycle from toppling to the side. Figure 5 shows the example of an electric unicycle with these features.

Figure 5: Electric Unicycle with Handlebar (SuperRideUnicycle, n.d.)

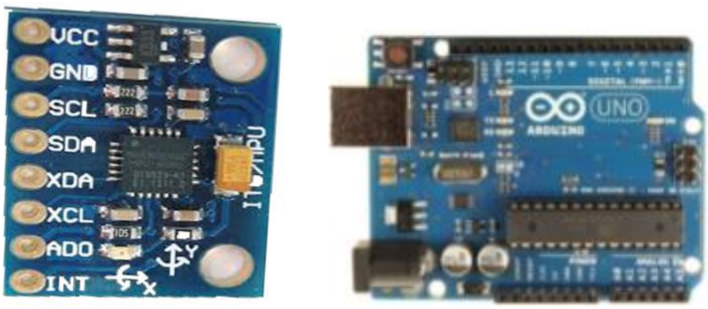
2.2 Components of Electric Unicycle

The common components used in an electric unicycle are sensor unit, controller unit, motor, battery, casing, wheel, and structure. The detailed study of the components that operated most unicycle in the market is discussed as follows:

2.2.1 Sensor unit

The sensor in the unicycle is the crucial component as it is the part that makes the electric unicycle become a self-balancing vehicle. A sensor is a component of which can give exact track of motions. Motion tracking technology can transform user position into data readable by the microcontroller (Srikanth, 2015). Gyroscope and accelerometer are the standard sensors that are used widely in many types of unicycles. A gyroscope is a device that is used to measure angular velocity. Gyroscope is commonly found with an accelerometer for applications such as vehicle navigation and motion-capture. The function is quite the same with an accelerometer, but the difference is it can provide exact information on how some object is oriented (Mucheru, 2014).

For example, in the I-Cycle, the MPU-6050 sensor act as a gyroscope and accelerometer at the same time. It can integrate a 6-axis motion tracking device that merges a 3-axis gyroscope, a 3-axis accelerometer, and a digital motion processor (DMP) all in a tiny 4×4×0.9mm package, as shown in Figure 6(a). For precision tracking of both fast and slow motions, the parts feature a user-programmable Gyroscope full-scale range of ±250 to ±2000°/sec (DPS) and a user-programmable accelerometer full-scale range of ±2g to ±16g (Srikanth, 2015).



(a) (b)

Figure 6: (a) 6-Axis motion tracking device (MPU 6050) (b) Arduino UNO board

2.2.2 Control unit

The control unit acts like a brain for this vehicle. This unit controls the balance parameter to achieve the required stability. The control unit analyse the data from the sensor unit, i.e., the angle of tilt. Then the control unit transfers the signal to the motor driver to uphold the upright position of the vehicle (Srikanth, 2015). The commonly used controller is Arduino UNO, along with ATMEGA328, as shown in Figure 6(b).

2.2.3 Motor

The motor acts as locomotion for the unicycle as it allows the wheel of the unicycle to be rotated according to the feedback of the controller. The typical motor type used for the electric unicycle is Brushless Direct Current (BLDC) Hub Motor, as shown in Figure 7. This motor is a synchronous electric motor powered by direct-current electricity (DC) and has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes (Hazari et al., 2014; Kenjo & Nagamori, 1985).

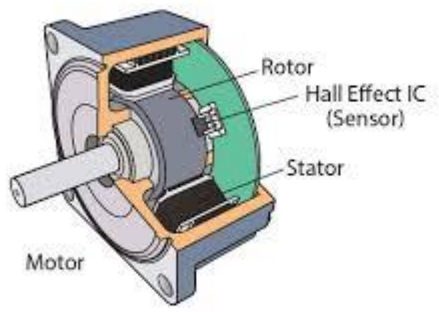


Figure 7: Brushless Direct Current (BLDC)

2.2.4 Battery

Rechargeable battery such as Lithium-Ion (Li-Ion), is usually used for the electric unicycle to make it portable and convenient. Chemicals used in Li-Ion batteries are lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), and lithium titanate (LTO) (Singh et al., 2015). Multiple battery cells can be integrated into a module. Multiple modules can be integrated into a battery pack (Deng, 2015). Figure 8 shows the Li-ion battery component.

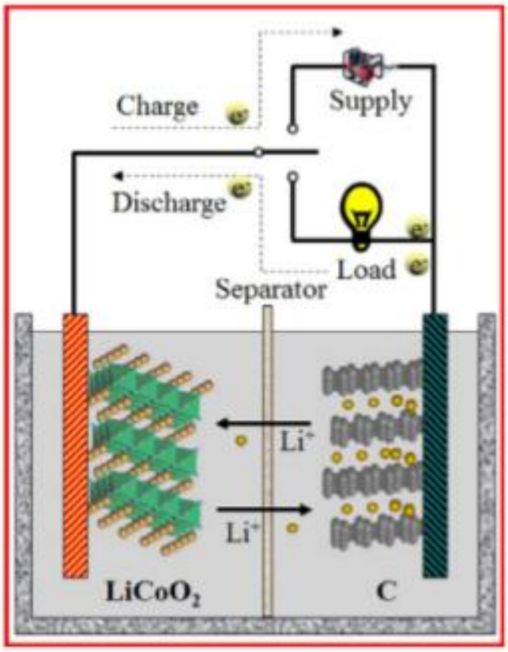


Figure 8: The essential components and operation principle of a Li-ion cell (Deng, 2015)

3.0 METHODOLOGY

This design work aims to build a stabilised electric unicycle that can ease the process of learning of riding an electric unicycle. Therefore, this work involved the process of planning, brainstorming, design finalizing, fabricating, and testing of the new stabilized electric unicycle. The workflow of this research is arranged in the flowchart in Figure 9.

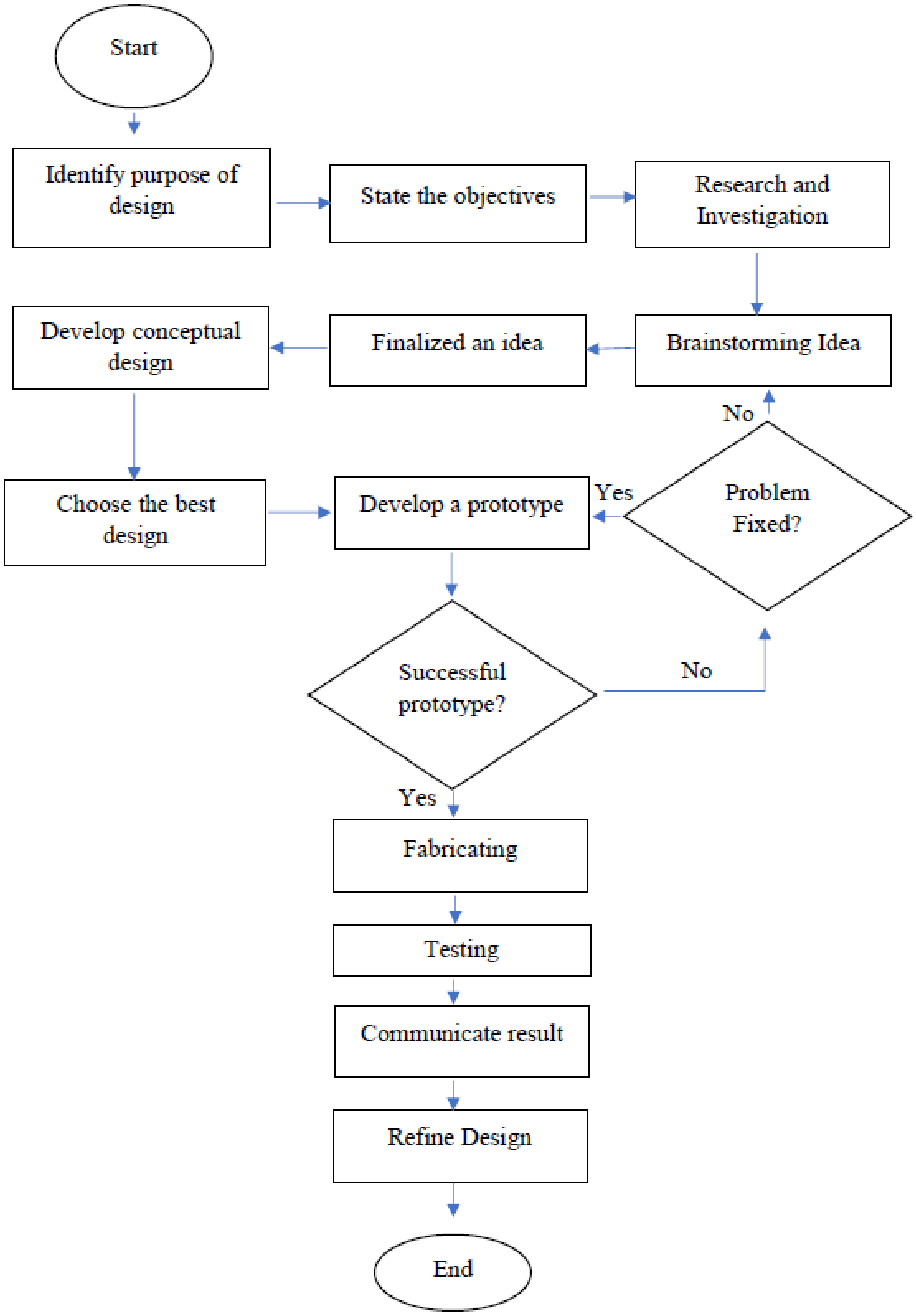


Figure 9: Flow chart of the methodology of electric unicycle design improvement

3.1 Conceptual Idea

This section covers the conceptual ideas that have been thought throughout the project on how to make the electric unicycle more stable. Basically, below are the ideas that have been brainstormed throughout the semester to add the stabilise feature on the basic electric unicycle:

3.1.1 Handle

Handle features can be added to give the user a sense of stability and safety. The handle is quite the same as a bicycle handlebar that acts as the mechanism of changing the orientation of the wheel. Foldable type or adjustable type of handlebars can be integrated into the electric unicycle to add the feature of ergonomic and flexibility that allows the various height of the handle to give comfort to the user. Figure 10 shows one type of handle that can be integrated into the electric unicycle.

Figure 10: Adjustable handle of the electric unicycle

3.1.2 Automatic stand with wheel

This feature can be added to the unicycle to assist the user in riding the unicycle. Through experience, the hardest part of riding an electric unicycle is to step both feet onto the pedal during the beginning of the ride. It is also difficult for the rider to stop the ride since one foot needs to be put on the ground to maintain the right-left balance while idling. Therefore, an automatic stand is proposed where the stand is activated during ride initiation to ease the user putting both feet on the pedals. When the ride speed rises to a certain value, the stand is folded to allow a smooth ride. In stopping the ride, when the speed drops to lower than the mentioned value, the stand is automatically unfolded to allow a stable stop. Therefore, the user can keep both feet on the pedals when stopping with the help of the stand.

3.1.3 Wide-wheel or double-wheel

The front-back balance is maintained by the self-balancing system in the unicycle. However, the right-left balance is solely dependent on the rider balancing skill. Changing the width of the wheel of the unicycle would be one way to assist the right-left balance of the unicycle. The larger the ground contact area, the greater the stability of the object. Thus, the unicycle stability can be improved by increasing the width of the wheel or by using a double wheel, as shown in Figure 11.

(a) (b)

Figure 11: (a) Double Wheel and (b) Wide wheel electric unicycles

Based on the three conceptual ideas stated above, the second idea, i.e., integration of the automatic support wheel into the electric unicycle, was chosen for this work. It is a good idea that can be fused into the electric unicycle due to its versatility, novelty, low manufacturing cost, and ease of fabrication.

3.2 Conceptual Design

From the selected design idea, namely the automatic support wheel, three conceptual designs related to the design idea have been proposed. The basic components of the automatic support wheel are the supporting wheel, shaft, and bracket to hold the shaft. The differences between all conceptual designs are mainly the shapes and the supporting mechanism.

3.2.1 Concept 1

This design is featured with a cylinder shaft that is connected to a solid bracket (Figure 12). A lever with a wheel is attached at the bottom part of the bracket with bolt and nut. The lever and wheel are folded by using a motor connected to the cylinder shaft. Solid metal is used to fabricate the bracket and the shaft to allow easy manufacturing process, strong structure, and minimize the number of components in the supporting wheel system.

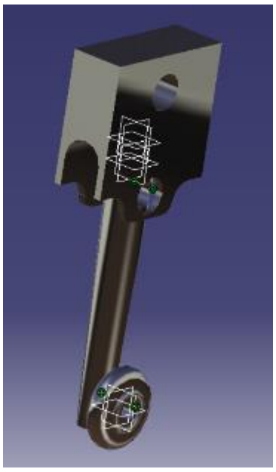


Figure 12: Conceptual design 1

3.2.2 Concept 2

The second conceptual design is more compact than the first design (Figure 13). The design consists of two rectangular solid metals that are connected by hinges. The bottom box includes a supporting wheel. By using a spring, the bottom rectangular box can be folded to the side of the upper rectangular box. The folding mechanism is manually activated and triggered when the wheel receives enough friction force from the ride. The design is simple and does not include any electricity.

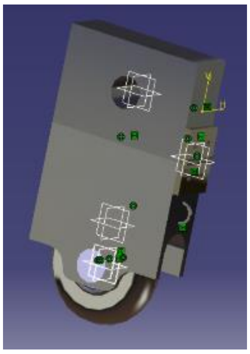


Figure 13: Conceptual design 2

3.2.3 Concept 3

The third design is the simplest as it only consists of two components, which are the hollow metal and a wheel (Figure 14). The wheel is attached to the cuboid structure. To operate the support wheel, a shaft with coupling is attached with the hollow cuboid, and another end of the shaft is connected to the DC motor. The folding mechanism is similar to the concept of one design. The fabrication is a little difficult due to the hollow cuboid component, but it can reduce weight.

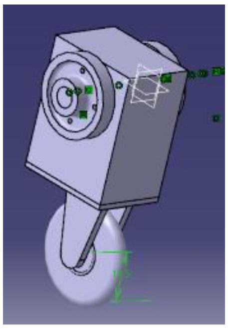


Figure 14: Conceptual design 3

3.3 Design Selection

After the process of brainstorming the idea of generating the conceptual design, the final design selection process should be done. Based on the market investigation, the design for the support wheel for electric unicycle is not available in the market. This means the design of a support wheel for an electric unicycle is new to the industry. Therefore, no reference design can act as a datum for the design selection. Further discussion has been made to choose the best design. The factors that were taken into consideration is the size of the design, weight, fabrication process, and the mechanism of the design. Based on the discussion with the supervisor, conceptual design three is chosen because it fits all the criteria needed to be integrated into the electric unicycle.

3.4 Drawing and Simulation Processes

After the design selection was completed, the selected design went through a drawing and simulation process by using appropriate tools. The drawing process utilises CATIA V5 design software to create 3D models followed by engineering detail drawings of the finalised design. Stress analysis simulation is conducted to investigate the strength of the design structure. This simulation is important to reduce the chance of failure that could happen during the testing process. The finite element method software used to simulate the design strength is ANSYS. In addition, the Arduino system is used as a control system in managing the automatic component in the selected design concept.

3.5 Final Design

The final design has two additional support wheels below the pedals. The support wheels add two contact points to the ground, each located 14.5cm laterally from the centre wheel. The weight of the user, *W*, is divided into 2 points, each located around 10.8cm laterally from the centre wheel. The addition of support wheels significantly increases the stability of the unicycle by increasing the contact point to the ground from 1 point to 3 points, as shown in Figure 15.

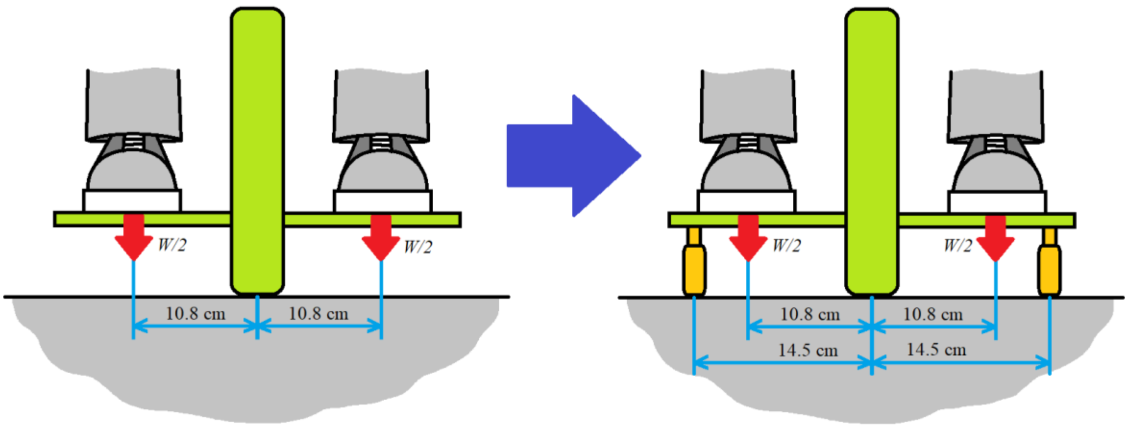
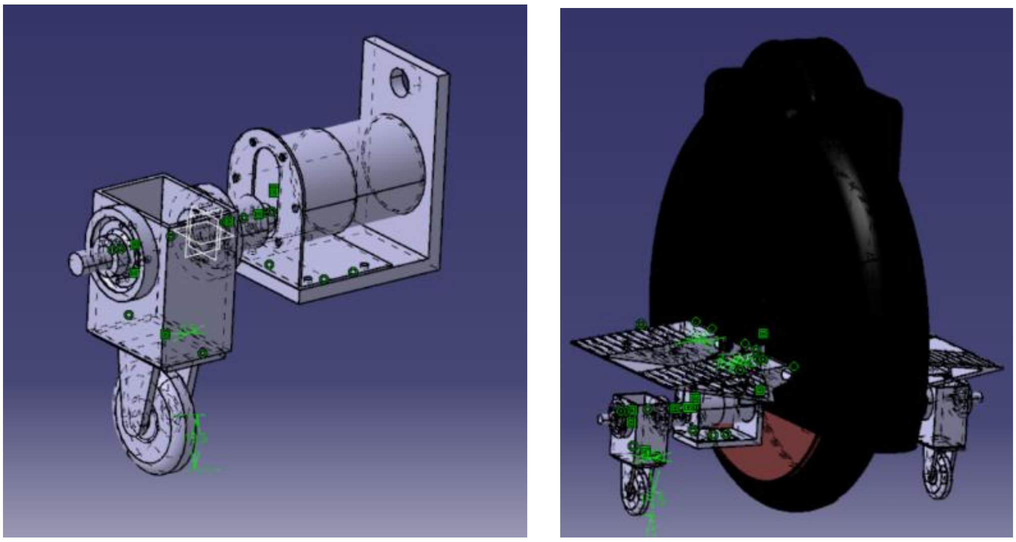


Figure 15: The improvement of the unicycle stability by adding ground contact points

The final design drawing includes the system that will operate the support wheel, which is the DC Motor. The motor will be fixed into the bracket and will be connected to the L-support. The L-support is connected to the wheel holder of an electric unicycle. The motor will be integrated into an Arduino board and Motor Bridge L2998N that allows the user to control the support wheel. Figure 16(a) shows the design of the support wheel connected to the motor. The overall view of the support wheel that is assembled into the electric unicycle is shown in Figure 16(b).



(a) (b)

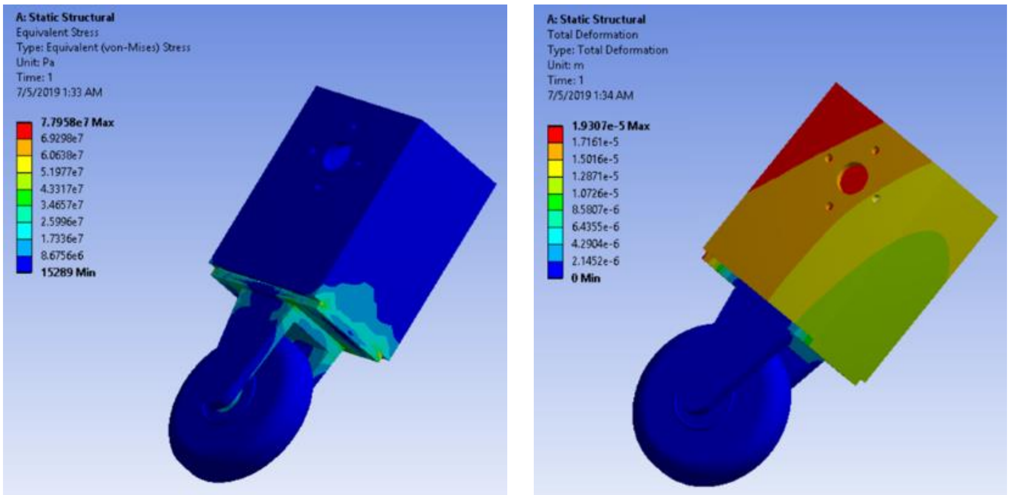
Figure 16: (a) Finalized design of support wheel, (b) Assembly design of support wheel and electric unicycle

3.6 Design Analysis

Design analysis involves the process of simulating the final design by using finite element method software. The software used is ANSYS 14.5, which can analyse the static structural effect on the current design. For example, we can obtain the data of the maximum stress, the total deformation, and then the safety factor of the design can be decided. Static structural analysis has been done to determine whether the final design of the support wheel can withstand the maximum load of 100kg. The maximum load is determined by the manufacturer of the electric unicycle that stated that the maximum weight of a person that can use the unicycle is 100kg. In this simulation, 50kg of the load is acting on the support, as each support can hold up to only 50kg load.

The simulation is divided into two parts, which are the stand with the wheel and the shaft that is connected to the coupling with DC Motor. Figure 17(a) shows the equivalent stress (Von-Misses) that acted on the stand. The load acted on the stand is set to be 50kg that is directed downward at the top parts of the stand. The wheel of the stand is selected as the fixed support for the body. Based on the result obtained, the maximum stress occurs between the joint of the wheel with the hollow-square metal that basically the stand. The value of the maximum stress is $7.79 \times 10^7 Pa$. The illustration obtained shows that there is no fracture or body failure occurred when 50kg of the load is acting on the stands.

The other result obtained from the simulation is the total deformation of the stand. Total deformation in Figure 17(b) shows which part of the stand is deflected when a certain load or force is applied to the stand. The red coloured area indicated the location of the stand that is affected the most based on the load applied. The value of maximum total deformation is 1.9307×10^{-5}m. The small value of maximum total deformation denotes that the stand can withstand the load of 50kg when acted on the stand.

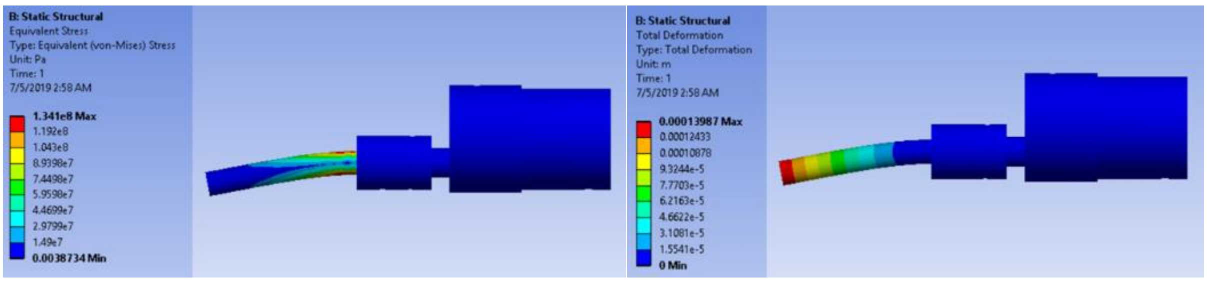


(a) (b)

Figure 17: (a) Equivalent stress (Von-Misses) of the stand, (b) Total deformation of stand

Another simulation is performed focusing on the shaft that is supported the stand before. The structure of the shaft is that it is connected to the coupling that is connected to the motor shaft. The motor is fixed with a bracket that is fixed to the L-support. The purpose of this simulation is to determine whether the shaft can hold the load of 50kg or otherwise. The same types of results are obtained with the stands before, which is the equivalent stress and the total deformation. The load is selected to be acted on the shaft with a downwards direction. Figure 18(a) shows the equivalent stress result.

Based on the result above, the maximum stress occurs in the area of the shaft near the coupling that causing a bit of bending. The value of maximum stress is 1.341×10^{8}Pa. The figure shows no failure or fracture happens to the shaft when the load is applied. Instead, a little bit of bending has occurred, and the total deformation result will show the value of the deflection of the shaft. Figure 18(b) shows the total deformation occurs at the shaft when a 50kg load is added. The value of the maximum total deformation is 0.00013987m. The value is literally low meaning that, there is only a small deflection has occurred to the shaft.



(a) (b)

Figure 18: (a) Equivalent stress (Von-Misses) of the shaft, (b) Total deformation on the shaft

3.7 Fabrication Process

The fabrication process consists of two main components, namely machining and wiring.

3.7.1 Machining

i. Milling Machine - The milling process is used to make a hole or drilling holes into the metal. The drilling process involves some part of the support wheel, which is the stand, L-support, and rim holder of the electric unicycle. The hole is made for the joining process of parts by using bolt and nut.

ii. Metal Cutter - Metal cutting is used to cut the metal bar into a specific dimension. The metal is used to make the L-support, which will be placed in a DC motor on top of it. The L-support will be connected to the rim holder of the electric unicycle.

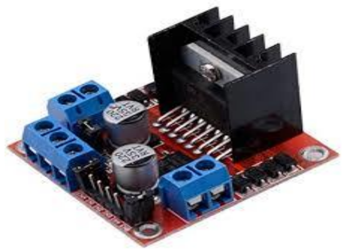
iii. Grinder Machine - The grinding process is the post-process after any drilling and cutting process. This is because the product of drilling and cutting will usually cause the surface of that affected by the process to be rough. The grinding process will make the surface to be smoother that soon will ease the process of assembling.

iv. Welding Machine - The L-support was made from two metal bars. In order to join the metal bar into an L-shape, the process of welding is involved. Welding will allow the joint to be much stronger to support all the force applied to the support. The wheel and the stands are also connected by welding the square-hollow metal section to the body of the wheel.

3.7.2 Wiring

The wiring process involves a circuit connection that allows the user to control the support wheel added to the electric unicycle. Figure 19 shows the components required to complete the wiring system.

(a) Arduino UNO



(b) Dual Motor Driver L298N

(c) Bluetooth Module HC-06

(d) DC Motor

(e) 9V Battery

(f) Connecting Wire

Figure 19: Components of the Arduino system for support wheels

The schematic diagram was sketched using the EasyEDA software that allows the user to create a new circuit and running a simulation to determine whether the circuit connection is correct or otherwise. The schematic is based on the system components that have been assembled into the electric unicycle to operate the support wheel. Figure 20 shows the circuit connection using the components stated above.

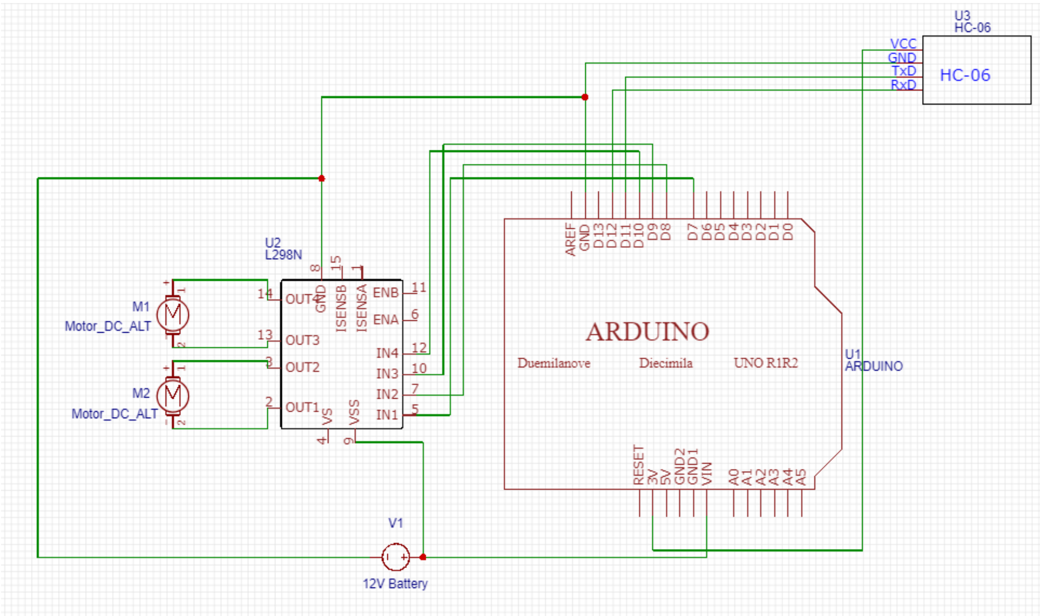


Figure 20: Schematic diagram for the circuit connection

The system applied to the support wheel is to allow the user to control the support wheel by using their smartphone. The reason why the smartphone is chosen to be remote to control the support wheel is simply that nowadays, almost everyone acquired a smartphone. The use of an extra remote controller to control the support wheel is not necessary. Instead, by simply using a smartphone, the user is able to control the support wheel. After the process of connecting all the components, the further process needs to be done, which is to upload the coding to the Arduino board. The coding was created to allow the user to control the support wheel by using a smartphone and to control the movement of the motor when feedback is transmitted from smartphones. It is suggested that the wheels fold out at riding speed lower than 10km/h and fold in at riding speed higher than 10 km/h to increase stability at low speed.

4.0 RESULT AND DISCUSSION

4.1 Final Fabricated Product

After completing all the fabrication processes, the final product, i.e., the assembly of the electric unicycle and the support wheels, is achieved, as shown in Figure 21.

Figure 21: Fabricated product

4.2 Mechanism – Arduino System

The support wheel fabricated is connected to the Arduino board to control its activation. Based on the coding designed, the support wheel is controlled by the feedback obtained from a Bluetooth device, as shown in Figure 22. The use of Bluetooth Module HC-06 is to allow the user to control the support wheel by using Bluetooth connection; in this case, it is the smartphone. An application called Bluetooth Terminal is used, which acted as the serial monitor for the Arduino system.

(a) (b)

Figure 22: Supporting wheels position when (a) number '1' is pressed (b) number '2' is pressed

4.3 Validation Test

A validation test is conducted to determine whether the new stabilized unicycle is better than the original unicycle. The test is conducted in UPM and involves five students who volunteer to take the test. The volunteers need to learn to ride the new stabilized unicycle and the original unicycle, as shown in Figure 23, to compare the two unicycles' levels of easiness. Figure 24 shows a volunteer rides the new stabilised unicycle and the original unicycle. After experiencing the differences between the two unicycles, the volunteer gave feedback on which unicycle is better in terms of ease of use. The feedback from the five volunteers is tabulated in Table 1.

Figure 23: Original unicycle without support wheel

(a) (b)

Figure 24: A volunteer riding (a) the original and (b) the new stabilised unicycle

Table 1: Result of validation test

Volunteer	Testimony		
	Standing on the unicycle: The prototype has better stability than the original unicycle	**Placing both feet on the pedals of the unicycle:** The prototype is easier than the original unicycle	**Forward movement:** The prototype has better stability than the original unicycle
A	Yes	Yes	Yes
B	Yes	Yes	Yes
C	Yes	Yes	Yes
D	Yes	Yes	Yes
E	Yes	Yes	No

Based on the feedback in Table 1, all volunteers justify that it is easier to stand on the new stabilized unicycle compare to the original unicycle. All volunteers also claimed that the new stabilized unicycle is easier to step on both pedals due to the presents of the support wheels. The support wheels successfully increase the contact area perpendicular to the motion direction and thus increase the lateral stability. Most of the volunteers also agree that the forward movement has better stability in the new unicycle. However, in terms of size, the original unicycle is better as the pedal can be flip to reduce its width and thus reduce its size and can be easily stored in a small space. This drawback can be solved if the support wheels are foldable or detachable while not in use. Hence, from the validation test conducted, the new design of the unicycle has better stability. Further modification can be made in the future to overcome the drawbacks encountered during the test.

5.0 CONCLUSION

In conclusion, the modification to stabilise the electric unicycle was completed. The design of a stabilised electric unicycle is fabricated at the end of the project. The product of fabrication is shown in the discussion section showing the assembled support wheel with the original unicycle. The product was managed to be fabricated according to the selected design concept. Based on the result of the validation test, the modified unicycle with support wheels has better stability than the original unicycle due to additional contact points with the ground. However, several emerging problems need to be catered to, such as the performance of the support wheels, the automatic feature, and the new unicycle's bulky shape. This finding is the starting point of allowing the unique vehicle to be used widely and thus propagates its benefit to society and the environment.

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