Develop a Long Range Drone For Wildlife Monitoring By Using Charging And Battery Replacement Pod Module.

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Abstract

In collaboration with the other project of developing a tricopter drone, the purpose of this project is to develop a long range drone by using charging and battery replacement pod module so that the drone is capable to fly over a long range for a long period to monitor the wildlife in the areas that are hardly reachable such as rainforest as there are dense growth of trees and tangled growth of vines and shrubs on the ground. This project will be focusing on the development the pod module. The design in this project is based on the features and specifications of the tricopter. The pod module is developed for the drone to replenish its battery autonomously. The mechanism of the pod module is controlled by using a direct current motor (DC motor) mounted with a lead screw to push and pull the battery slots along the pod module for battery swapping purpose. Two limit switches are used to control the movements of the battery slots. The DC motor and the limit switches are controlled by using MATLAB Simulink and programming the Arduino Uno Board which is connected to them. As an idea for wildlife monitoring, a few stations for charging and battery replacement can be placed in the desired area to ensure a long range flight of the drone. First, the Tricopter was designed so that it can land on the battery changing platform which the landing gears are framed to meet the platform design as the drone has to be in a fixed position for battery replacement after landing.

1. INTRODUCTION

One of the most efficient ways for wildlife monitoring is by using drones. These drones which are also known as unmanned aerial vehicles (UAVs), which is an aircraft with no pilot on board. UAVs have features that are suitable for wildlife monitoring such as the drone is able to cover a large area monitoring, it provides GPS location tracking, the drone can be equipped with cameras and sensors to aid in wildlife inspection and so on.

Due to limited on-board power supply, the drones will have short flight time and are constrained in their long-term functionality [1]. Normally, a rechargeable battery takes longer time to recharge compared to the time taken to discharge as power supply. Typically, a LiPo battery for drone requires a recharging time of 1 to 2 hours to provide a flight time of around 15 minutes. This is quite unrealistic for long-term surveillance activities such as wildlife monitoring which often requires a long period observation.

Wildlife monitoring is the method by which the position and health of wildlife and game is controlled [2]. Wildlife monitoring for a large area such as a rainforest requires a drone which can fly for a long range for a long period of time. Generally, a drone has a short average flight time. Charging and battery replacement stations are designed to replenish the drone's battery regularly before it depletes. The charging and battery replacement pod module can be solar powered since there is no power supply in rainforests. The flight path of the drone is programmable so that it will start searching for the nearest charging station when its battery power drops to a certain low percentage. The drone can also be programmed to find its way to land on the charging and battery replacement pod module to charge or replace its battery autonomously. The general plan idea of the flight path and the locations set for battery replacement stations in a rainforest is as shown in Figure 1. The battery replacement stations are set at a regular distance between one another in a selected area of the rainforest for the drone to replace its battery before its battery depletes. A thermal camera can be equipped to the drone to monitor the wildlife as thermal camera enables us to observe the animal body temperature [3].

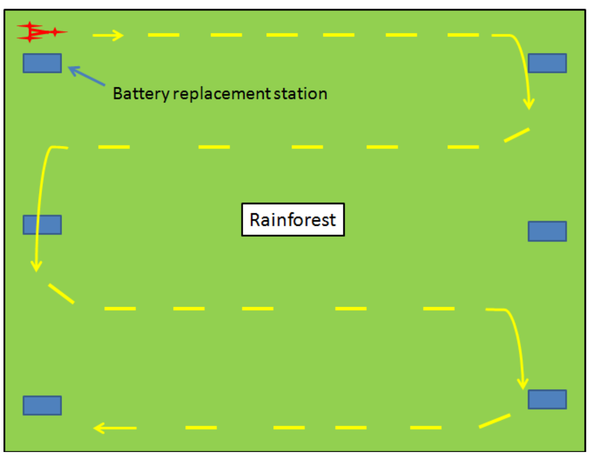

Figure 1: General plan idea of location set for charging and battery replacement stations [4].

Tricopter is basically a UAV (Unmanned Aerial Vehicle) built with three rotors, two of them are fixed rotors and one of them is attached to a servo as the tail of the Tricopter. The two fixed rotors are spinning in opposite directions but the tail rotor produces torque that tries to spin the tricopter, causing a resultant yawing moment. Therefore, the tail rotor can be tilted to compensate this torque [5].

UAV has become one of the best choice for surveillance purpose. This is because UAV is capable to rapidly survey large areas and it can obtain angles and reach places inaccessible from the ground. Besides, UAV is less obtrusive to wildlife as it can track or monitored the wildlife from a distance without disturbing the wildlife so that the natural life of the wildlife can be observed.[6]

Tricopter has higher average flight time than Quadcopter. A flight time of quadcopter will generally last between 10 and 15 minutes while that of a tricopter may last for 21 minutes due to its lesser weight and lesser power consumption.[7]

The objectives of this study are:

- to increase the flight duration of the drone by using charging and battery replacement pod module.
- to design a suitable battery casing and attaching method for ease of battery replacement

2. LITERATURE REVIEW

Over the past 3 years, the usage of drones has increased tremendously. According to the FAA report in early February of 2016, the number of drones on the national registry now takes over the number of registered traditional aircraft.[8] This shows that drones are widely used in various fields in the nation. This is due to the multifunctional characteristics of the drones. Additionally, drones have small size and have light weight which are easy to be handled. Most drones on today's market are "micro-drones" which have weight less than 2 kg. However, drones offer flight time of only ranging from 10 to 30 minutes.[8] Majority of the drones are multirotors which offer more stability to hover in the air and this feature suits surveillance purpose such as wildlife monitoring.

The first prototype of an autonomous UAV battery recharge landing station was developed by Daniel R. Dale in 2007.[9, 10] This landing station was used to conduct the first fully autonomous and long-term flight test with quadcopter. This battery recharge system aimed to recharge the batteries of UAVs during long duration missions. Commercial lithium polymer battery charger requires human intervention to manually activate the charging process. In [9], an AT-MEGA128 microcontroller on a Robostix board was used to control the lithium polymer battery charger. This microcontroller acts like the brain of the recharge system that controls the charging process while interacting with external computers.[9, 11]

Lead screws convert rotary motion to linear motion. If an application requires more thrust, a larger diameter of the screw will be needed. [12] This is because the screw is similar to a cylindrical object which is subject to compression and tension. The screw should not deflect during compression and during tension, the screw should be able to support the load without experiencing failure. The efficiency of the lead screw in converting rotary motion to linear motion depends on the thread type of the screw.[13] Acme threads are the cheapest but they are among the least efficient ones. Threads with higher efficiencies and low friction are buttress threads and square threads. Also, lead screws have advantages such as they possess a relatively high load carry capacity. However, the relatively high degree of friction on the threads may cause the threads to wear quickly.

A DC motor is a device that converts electrical energy into mechanical energy in the form of rotary motion.[14] There are DC motors with gear down which acts to increase torque and reduce rpm.[15] A higher torque motor driving a lead screw will produce higher force for linear motion to push or push the object of high weight.

Lithium polymer batteries (LiPo batteries) have a few advantages over the common Nickel-Metal (NiMH) or Nickel Cadmium (NiCd) batteries such as, the LiPo batteries are much lighter weight, higher capacities and higher discharge rates.[16, 17] A LiPo cell has a nominal voltage of 3.7V. The voltage of a LiPo pack depends on the number of LiPo cells in the pack. Voltage determines the speed of rotation of the electric motor.[16] The capacity of a battery implies how much power the battery can hold. The unit is in milliamp hours (mAh). However, the larger the capacity, the larger the physical size and weight of the battery. Therefore, it is important to optimize the capacity for better performance of the drone in consideration of increase in size and weight. The discharge rate of a battery means how fast a battery can be discharged safely. The discharge rate of a battery is often called “C” rating. Theoretically, a battery with a discharge rating of 15C would safely discharge at a rate 15 times more than the capacity of the pack.[17]

3. METHODOLOGY

The were 2 designs for the charging and battery replacement pod modules. The results of the first design was unsatisfactory. Thus, the design was improved to achieve the objectives of this project. The results will be discussed in the later section.

3.1. Design I

3.1.1. Battery Casing Design

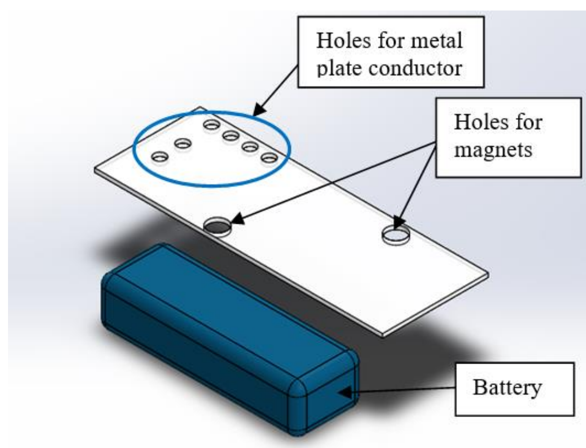

Figure 2: First battery casing design.

The battery casing was first designed in order to be easily attached to and detached from the tricopter. The battery casing should be light to reduce the overall weight of the tricopter. In this project, perspex was selected as the material for the battery casing. The battery casing should also have the features such that the battery can be easily connected to the tricopter as a power supply. Figure 2 shows the first design of the battery casing with the battery.

The battery casing design was simple as it was just a perspex plate attaching on top of the LiPo battery with cable tie wrapping over it. There were six smaller holes which were for each of the wires from the LiPo battery to pass through and connect with the metal plate conductors by soldering. The material used for the metal plate conductors was steel. The desired dimensions of the steel plate were first measured and it was deformed and shaped to pass through the hole on the battery casing. The other three larger holes at both sides of the perspex plate were for the magnets to be inserted into them as the attaching method to the tricopter was by using the magnetic force. The magnets had to be strong enough to hold the weight of the battery plus the casing. A similar perspex plate was made which was to be mounted underneath the tricopter.

3.1.2. Battery Replacement Platform and Servo Motor Control

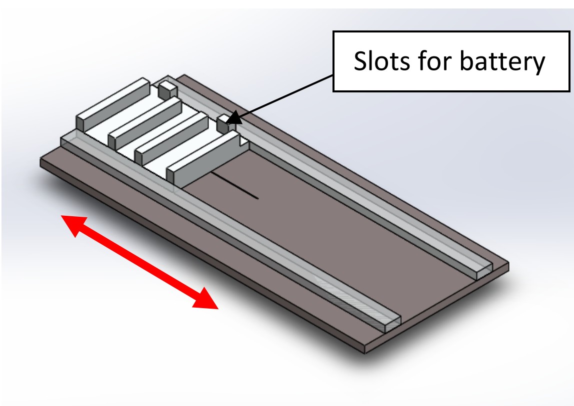

Figure 3: Battery recharging and replacement platform.

From Figure 3, the 2 slots on a sliding plate were designed for battery replacement. The sliding plate was made of perspex. It was designed to slide along the platform to and fro along the track line. The linear motion on the platform was controlled by a servo motor underneath the platform as shown in Figure 4.

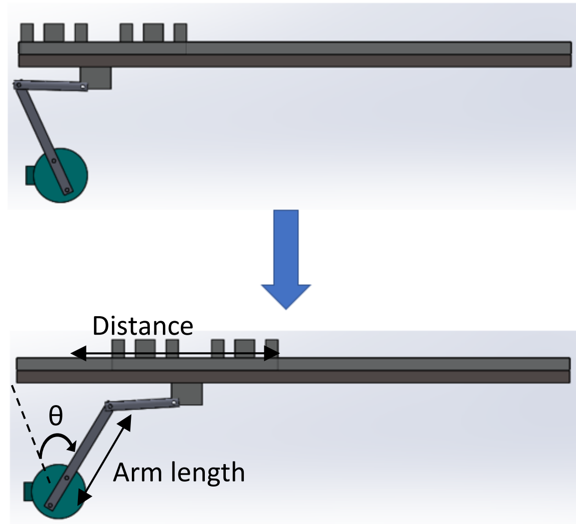

Figure 4: Sliding mechanism controlled by a servo motor.

The servo motor was equipped with an arm and the arm was pivotted to the thin plate connected with the sliding plate to move the battery slots along the track line. The distance travelled by the battery slots can be calculated by equation (1) shown below.

$$Distance\ travelled = 2\ Arm\ length \times \sin\frac{\theta}{2} \qquad (1)$$

Where θ = turn angle of the servo motor

The servo motor was programmed and controlled with Arduino Uno board. The simulation was run with MATLAB Simulink.

3.1.3. Battery Recharging System

Figure 5 shows the battery recharging and replacement platform with 2 ports for battery recharging so that the depleted battery can be recharged in either one of the recharging ports. There were 2 thin perspex plates which acted as the ports for battery recharge. The design of the thin perspex plates were similar to the battery casing so that the battery can be fitted on it during recharging process.

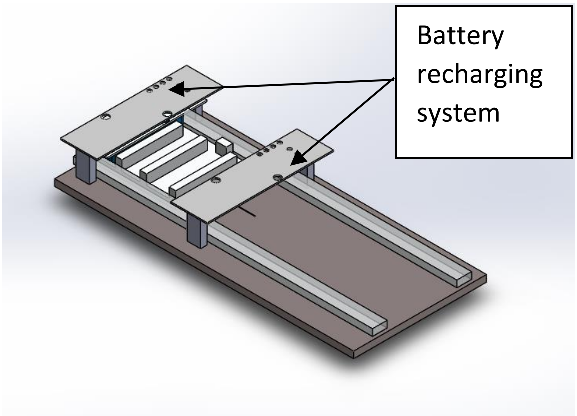

Figure 5: Battery recharging and replacement platform with recharging system.

3.1.4. Battery Swapping Mechanism

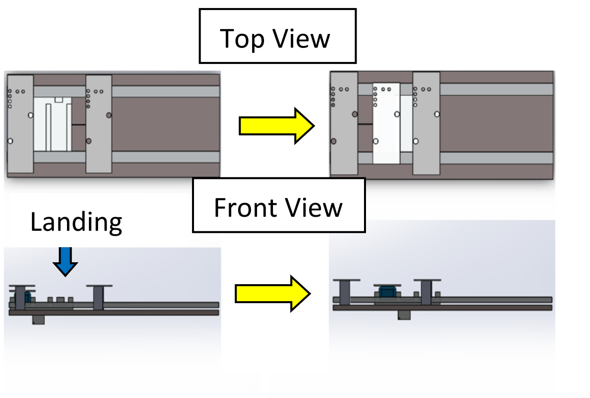

Figure 6: Battery swapping mechanism.

From Figure 6, there is a LiPo battery ready in one of the battery slots at the sliding plate on the platform. The empty battery slot is at the middle which is ready for the depleted battery from the tricopter to be placed into it after landing. Once the battery from the tricopter is placed into the empty battery slot on the platform, the servo motor will push the sliding plate horizontally to detach the battery from the tricopter. Thereafter, the battery from the tricopter will be reaching at the recharging port where the depleted battery will be recharged. Simultaneously, as the sliding plate slides horizontally, the fully-charged battery which is ready on the platform will move to the middle where it is just below the tricopter. The fully-charged battery will then be pulled to the tricopter by magnetic attraction of the magnets, attaching to the tricopter.

3.2. Design II

3.2.1. Battery Casing Design

The second design of the battery casing was almost the same as the first design. The only difference was that there was an extra hole at the middle of the perspex plate for an extra magnet to be inserted into it. This was to strengthen the holding force to the tricopter.

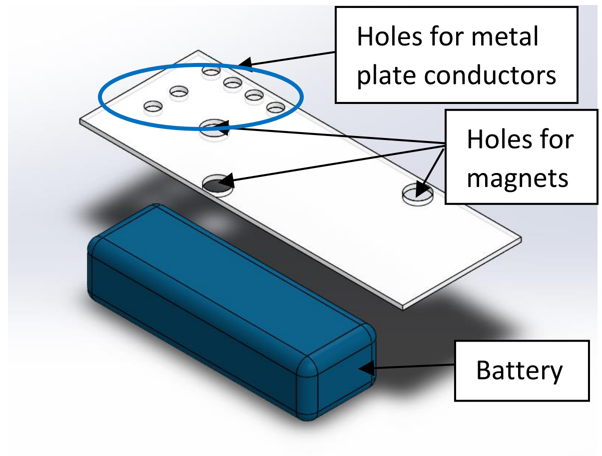

Figure 7: Second battery casing design.

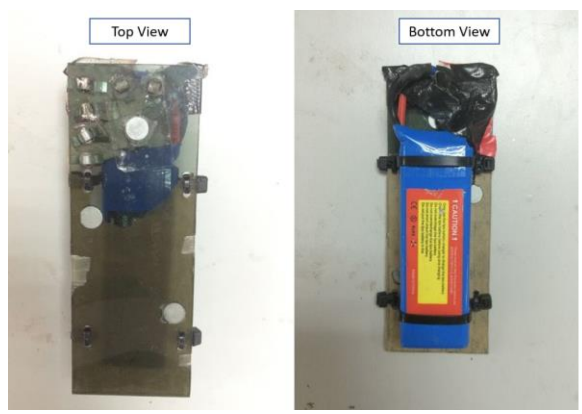

Figure 8: Prototype of battery casing.

Figure 8 shows the prototype of the battery casing with battery. After all the wires were connected to the steel plate conductor by soldering, the wirings were fixed by using duct tape. The purpose of using duct tape was also to prevent the wires from contacting and causing short circuit. This was a safety precaution as the LiPo battery produces high current. It might cause explosion and the power source might be destroyed.[18]

3.2.2. Battery Replacement Platform and DC Motor Control

The battery replacement platform design did not change in Design II. Refer to Figure 3, the beams at each side of the sliding plate create a track which guides the sliding motion of the sliding plates and it ensures the movements of the sliding plate is always straight. Its linear movement was controlled by using a combination of a lead screw and a direct current motor (DC motor).

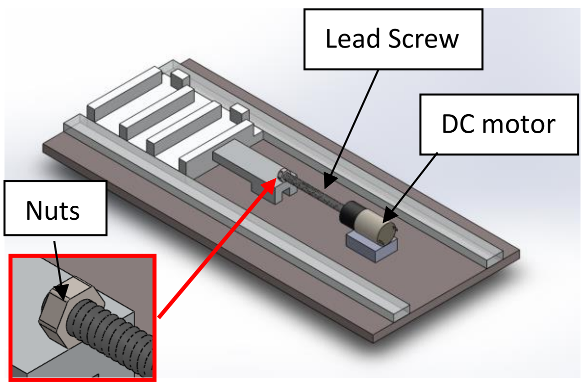

Figure 9: Sliding mechanism controlled by DC motor.

From Figure 9, there was an extra block attached on the sliding plate at the side and there was a nut attached on the extra block which was for the lead screw to be engaged in it to produce linear motion from rotary motion of the DC motor. The DC motor was fixed at its position by using cable tie. The lead screw converts the rotary motion to linear motion by using the helix angle of the thread. The performance of the lead screw is highly dependent on the coefficient of friction between the nut and the screw.[19] Therefore, to improve the performance of the lead screw, lubricant can be applied on it to reduce friction. The lead screw was mounted to the shaft of a DC motor. The DC motor used was a high torque DC motor with built-in gearbox. This was because larger force is required to push or pull two batteries along the track. However, the speed of rotation of the high torque DC motor was low.

The linear motion of the sliding plate was such that the clockwise rotation of the DC motor will pull the sliding plate towards the DC motor while the anticlockwise rotation of the DC motor will push the sliding plate away from the DC motor. The direction of rotation of the DC motor was controlled by an Arduino Uno Board connected with 4 relays. The motor control was first programmed in Arduino and then the codes were imported into MATLAB Simulink to control the 4 relays as digital outputs. The circuit of the direction of rotation control is as shown as in Figure 5.

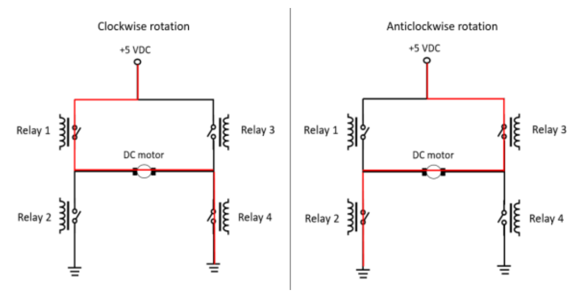

Figure 10: Circuit of relays controlling the direction of rotation of the DC motor

Figure 10 shows the circuit of relays which control the direction of rotation of the DC motor. The red lines indicate the connected circuit path. When Relay 1 and Relay 4 are turned ON while Relay 2 and 3 are turned OFF, the DC motor will produce clockwise rotation. When Relay 2 and Relay 3 are turned ON while Relay 1 and Relay 4 are turned OFF, the DC motor will produce anticlockwise rotation. The DC motor will stop turning if all the relays are turned OFF or only one relay is turned ON. It is not recommended to turn all the relays ON as the opposite flow of current may cause circuit connection failure.

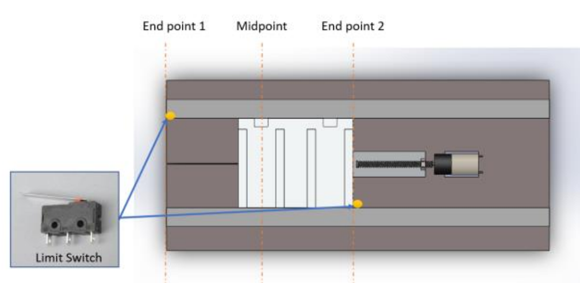

Figure 11: Position of limit switches.

From Figure 11, two limit switches were

placed at End point 1 and End point 2 respectively. The limit switches act as sensors to stop the sliding mechanism once the sliding plate reaches the limit switches.

3.2.3. Battery Recharging System

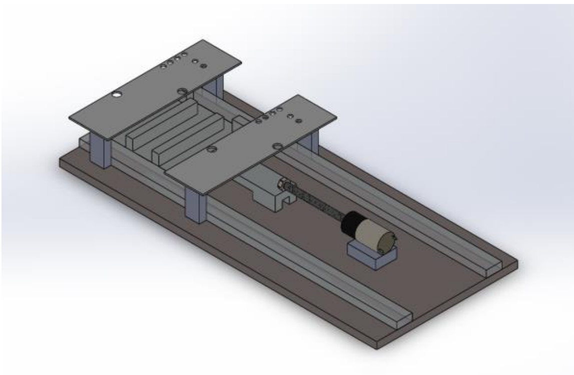

Figure 12: Battery pod module with recharging port.

The design of the battery recharging system remained unchanged as in Design I. Each of the two thin perspex plates which was similar to the battery casing was fixed at the End point 1 and End point 2 as shown in Figure 12. Both of the end points act as the battery recharging ports. The battery charger connectors were soldered with steel plates and were fixed on the battery recharging ports. The wires were covered with duct tapes to prevent short circuit as shown in Figure 13. The connectors can be connected to the battery charger for the recharging process.

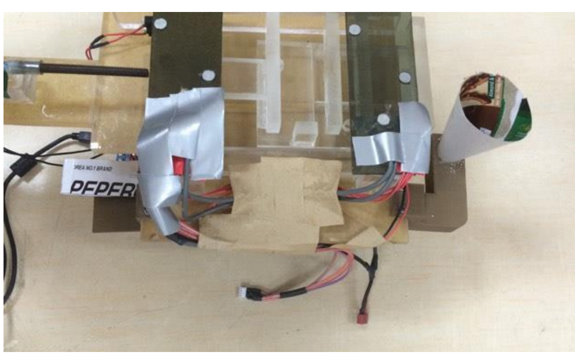

Figure 13: Battery charger connectors soldered at the recharging ports.

3.2.4. Landing Method and System Activation

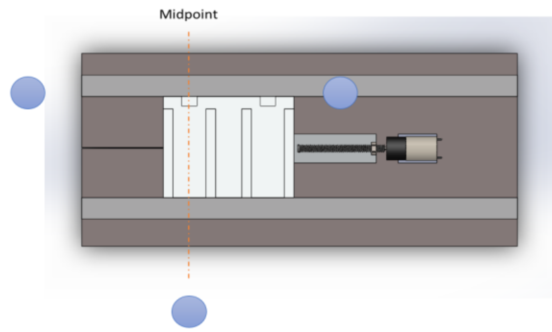

Figure 14: Landing gears position of the tricopter after landing.

For the battery on the tricopter to be inserted accurately into the battery slot at the Midpoint, the landing gears position was first determined. After that, three parts were designed to fix the landing gears on the battery replacement platform. The parts were drawn by using SOLIDWORKS as shown in Figure 15. Then, the parts were converted to STL file format and were printed by using a 3D printer.

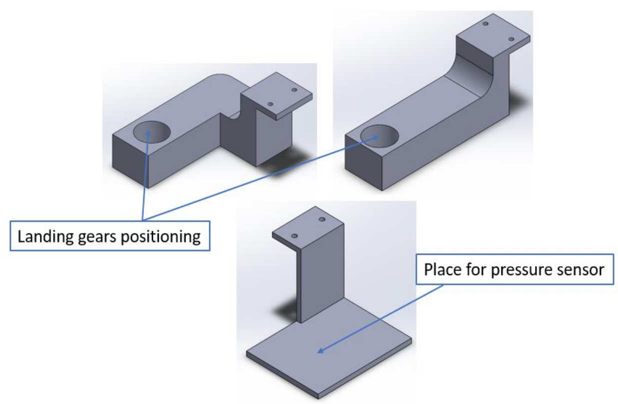

Figure 15: 3D drawings of the parts for landing gear positioning.

Two of the 3D parts were with holes which were just enough to fit the landing gears while the remaining 3D part was designed so that a pressure sensor can be placed on the landing surface. The 3D parts were fastened to the battery pod module with bolts and nuts as shown in Figure 16.

Figure 16: 3D part fixed on the battery pod module.

Two cones were made by using paperboard and they were glued around the holes of the 3D parts to guide the landing gear to reach the hole of the 3D part at the bottom upon landing.

A handmade pressure sensor was placed on the surface of the 3D part as shown in Figure 17. The pressure sensor was made of a combination of paperboard and aluminium foils attached with wires. The wires were connected to Arduino Uno board. The pressure sensor will trigger the whole process of battery swapping mechanism when it detects pressure acting on it. Upon landing, one of the landing gears of the tricopter will land on the pressure sensor. Once the pressure sensor detects the pressure acting on it, the Arduino Uno board will receive the signal and activate the DC motor.

3.2.5. Battery Swapping Mechanism

The battery swapping mechanism was first programmed in Arduino where the limit switches and the pressure sensors were the inputs while the 4 relays were the output which control the direction of rotation of the DC motor. The algorithm of the battery swapping mechanism is as shown in Figure 13. Firstly, as the tricopter lands on the platform, one of its landing gears will trigger the pressure sensor to send signal to the Arduino Uno board. Then, the DC motor will be activated and it will rotate, producing sliding motion of the sliding plate along the track. Once the sliding plate reaches one of the recharging port, the limit switch will send signal to the Arduino Uno board to deactivate the DC motor.

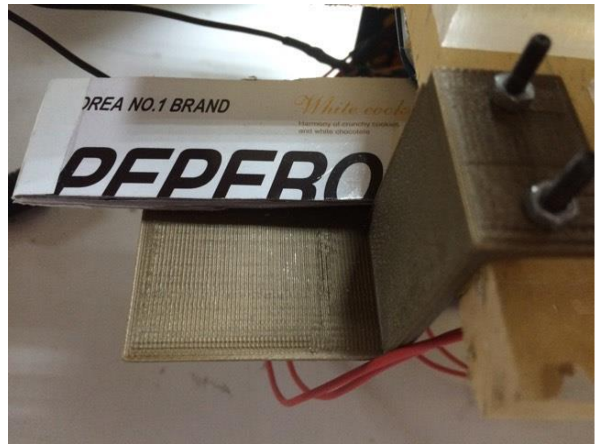

Figure 17: Top view of the 3D part with pressure sensor on the landing surface.

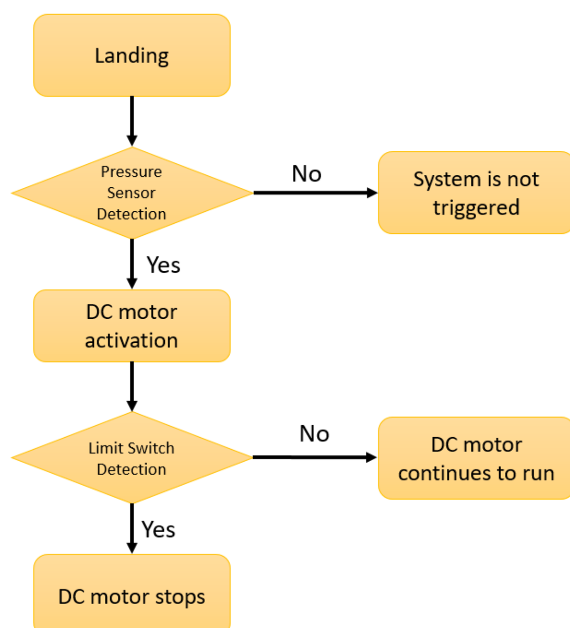

Figure 18: Algorithm of the battery swapping mechanism

Referring to Figure 19, in A, there is a fully charged battery ready in the right charging port. The battery is attaching to the charging port by magnetic force of attraction between the different poles of magnets. In B, the tricopter is landing on the platform after a long flight. The depleted battery beneath the tricopter will be placed into the empty slot accurately on the sliding plate with the guidance of the cones mentioned previously. After the tricopter lands, the pressure sensor will activate the DC motor to rotate the lead screw, pushing both the depleted battery and the fully charged battery towards the left recharging port. In C, the fully charged battery is pushed and the dislocation between the magnets will make the battery fall into the slot under it on the sliding plate. In D, the depleted battery eventually reaches the left recharging port and the sliding motion will stop when the limit switch at the left end of the platform is pressed by the sliding plate. The fully charged battery is under the tricopter. In E, the magnetic force of attraction between the magnets on the battery casing of the fully charged battery and the magnets at the bottom surface of the tricopter will pull the battery upwards, attaching to the tricopter. The tricopter is now ready to take off for another flight. Another cycle will be repeated when the depleted battery is fully recharged. The sliding plate will then move from the left to the right, which is the opposite direction during the next landing when the pressure sensor is triggered again.

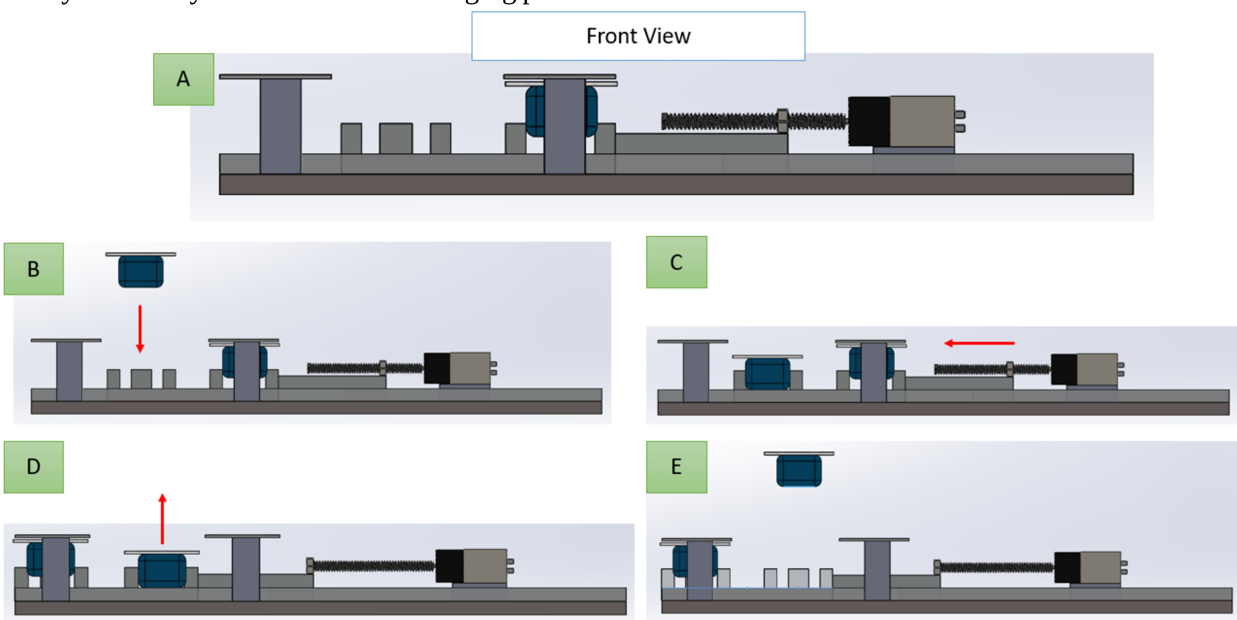

Figure 19: Working steps of the battery swapping mechanism from the front view.

4. RESULTS AND DISCUSSIONS

A. Design I

The first design in this project was unable to carry out the battery swapping mechanism. This was due to the low torque produced by the servo motor. The servo motor had no enough torque to push or pull the sliding plate in order to generate the sliding motion along the track line on the platform. This is because the total weight of the sliding plate plus 2 batteries are around 500g which is quite heavy. Moreover, the addition of an arm to the servo motor further decreases the resultant torque.

Figure 20 shows the response of the simulation done by using MATLAB Simulink where the start time of the simulation was first set at 1s. The result was that the sliding plate will move 8 cm horizontally in less than 1s until stationary after the mechanism was triggered. The mechanism was as simple as the sliding plate was only required to travel 8cm to and fro for battery swapping and recharging.

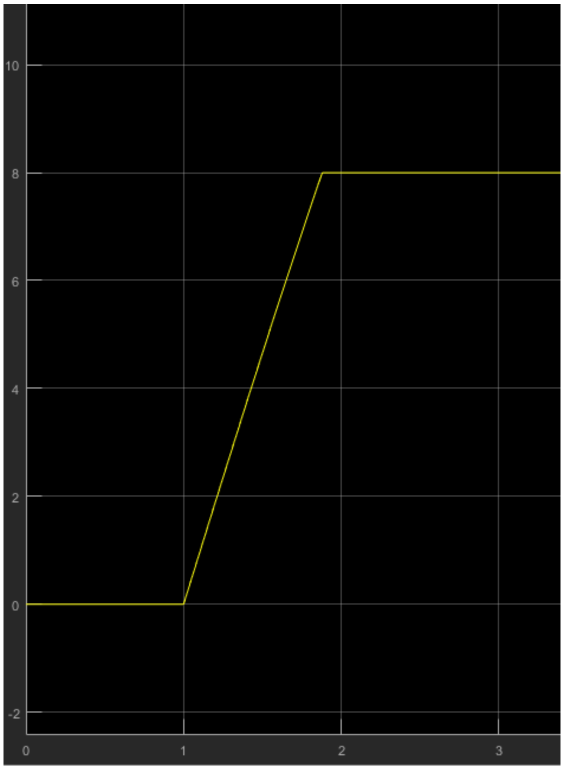

Figure 20: Distance travelled by the battery slots.

B. Design II

After the tricopter landed on the battery replacement platform, the battery swapping process was successfully carried out. The battery swapping process took about 2 to 3 minutes to complete since the speed of rotation of the DC motor is low. The sliding motion of the sliding plate was not smooth due to the lead screw was not properly mounted to the shaft of the DC motor.

From Figure 21, the lead screw was inserted into a rubber water pipe from the right end and it is glued with epoxy glue while the left end of the rubber water pipe was mounted to the DC motor shaft. Since there was an error in aligning the joint with the motor shaft when the epoxy glue was being cured, the rotation of the lead screw was slightly fluctuating vertically. Because of this, the linear motion of the sliding plate was not smooth.

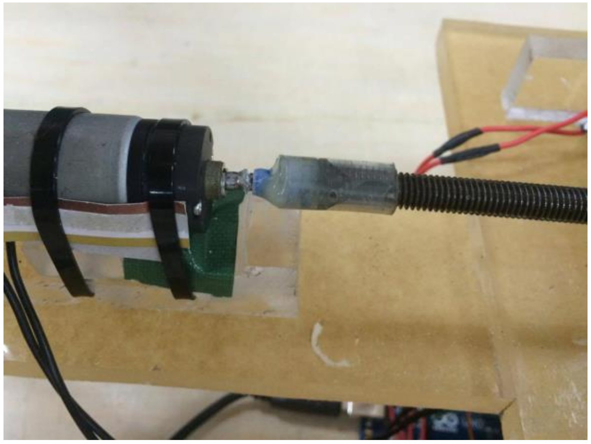

Figure 21: The joint of the lead screw with the DC motor shaft.

The battery swapping process was always successful when the sliding plate moved from the right towards the left recharging port. However, due to the limit switch at the left recharging port is not properly fixed at its position, the sliding plate sometimes failed to press the limit switch and thus, the sliding motion did not stop. The battery swapping process for the sliding plate moving from the left to the right was unsuccessful. This was because the sliding plate was being pulled by the lead screw, loosening the joint of the lead screw with the motor shaft. The joint was then detached from the motor shaft and failed to pull the sliding plate.

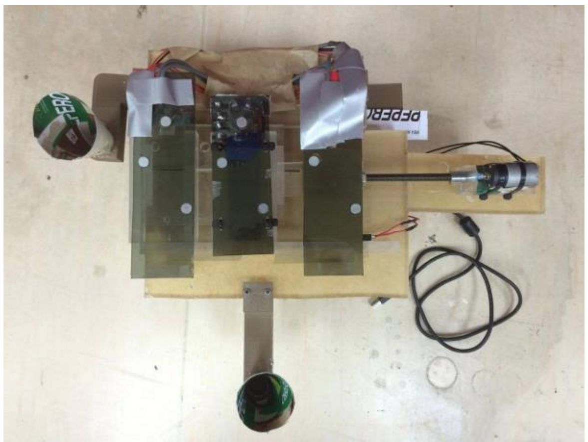

Figure 22: Top view of the battery replacement platform.

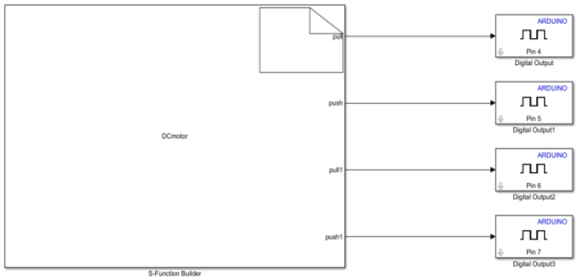

Figure 23: Relays control by using MATLAB Simulink.

The relays control by using MATLAB Simulink was successful. The S-Function Builder was used to interpret the Arduino program in order to control the pins connected to the relays as digital outputs which controlled the motor. Limit switch at the left end, limit switch at the right end and a pressure sensor were connected to the pin 8, 9 and 10 respectively as digital inputs while Relay 1, 2, 3 and 4 were connected to the pin 4, 5, 6 and 7 respectively. The response of the mechanism was tested prior to setting up the battery replacement prototype. The test result was such that, when the pressure sensor was pressed, the signal received at pin 10 was 1. If the initial condition of the left limit switch was 1 and the right limit switch was 0, pin 4 and pin 7 would set signal 1 to activate Relay 1 and 4 while pin 5 and 6 would set signal 0, deactivating Relay 2 and 3. Then, the DC motor started to rotate at clockwise direction. When the left limit switch was released, the DC motor continued to rotate at clockwise direction. When the right limit switch was pressed, the DC motor stopped rotating. Vice versa, the DC motor would rotate at anticlockwise direction when the pressure sensor was triggered again and the whole processes repeated the other way around for the initial condition as the right limit switch was pressed and left limit switch was released.

5. LIMITATIONS AND RECOMMENDATIONS

There are always limitations which restrict the outcome from going ideally. In this project, the prototype of the charging and battery replacement pod module was mostly handmade such as the cone for landing gears guidance, pressure sensor, shaping of the metal plate conductors and so on. The deviation from the desired shapes and dimensions was inevitable due to human errors.

Furthermore, limitation in 3D printing is one of the reasons of the imperfection of the prototype. The 3D printer failed to build parts of small dimensions. Therefore, the choice of fabricating small parts by using 3D printer was restricted. There were a few failures in 3D printing. Fail in printing 3D parts will result in waste of materials. The 3D drawing of the failure part was recreated to increase the minimum required dimensions to successfully print.

Lack of the parts or components required with desired dimensions in the market further increase the difficulty in achieving good performance of the prototype. For example, metal plate conductors with desired dimensions and shapes were hardly found. In this project, the metal plate conductors were made by cutting and shaping the steel shape with hands-on. Therefore, all the metal plate conductors produced were not exactly the same, causing difficulties in ensuring good surface contact between the battery casing and the drone for power supplying.

In addition, lack of resources such as materials further contributes to the imperfection of the prototype. For example, the metal plate conductors were made from a thin steel sheet since copper was hardly found in the laboratory. Also, the high torque DC motor with built-in gear box was old and it was reused in this project.

Time constraint is also one of the limitations in this project. There was too much time had been consumed for the Design I to be fabricated and tested. Therefore, there was no ample time to carry out the simulation and analysis for Design II once its fabrication was done.

6. CONCLUSION

In conclusion, this project has developed a charging and battery replacement prototype module to help in increasing the flight time of the tricopter. The battery replacement mechanism works successfully in ideal condition. The depleted battery is able to recharge at the recharging ports but with human intervention to manually turn on the battery charger.

Future works are important to be done so that the goal of having a fully autonomous charging and battery replacement pod module can be achieved. Without the limitations stated, we believe that the prototype module is capable to help in increasing the flight time of the tricopter effectively by saving the time for recharging the battery.

7. FUTURE WORK

As future work, an automated battery recharge system will be implemented in this prototype module as the current battery recharge system required human intervention to manually activate the battery charger. The battery charger will be implemented with a programmable microcontroller in order to activate the battery recharge system upon landing of the tricopter.

Furthermore, simulation and analysis for the battery swapping mechanism should be done to determine the performance of the system.

Other future work is an accurate landing method should be implemented in this prototype module. Studies regarding the combination of GPS tracking system and infrared sensor alignment will be performed with the goal of having fully autonomous landing system.

8. REFERENCES

1. M.C. Silverman, D.N., B. Jung, *Staying alive: A docking station for autonomous robot recharging.* IEEE, 2002.

2. *Wildlife & Game Monitoring.* Airborne Drones.

3. Fei, P.K., *Development of a DIY Tricopter with Quick Battery Replacement Design.* 2017.

4. Kong Joon Kit, P.K.F., *Develop A Long Range Drone For Wildlife Monitoring by Using Charging and Battery Replacement Pod Module.* Innovate Malaysia Design Competition 2017, 2017.

5. *How does a tricopter work.* Shrediquette.

6. David M. Bird, P., *Unmanned Vehicle Systems and Wildlife Management in the 21st Century.* McGill University, Montreal, 2014.

7. *Tricopter vs Quadcopter: Efficiency, Flight Time, And More.* RC Crunch, 2015.

8. Greygory M. Crutsinger, J.S., Roger Sollenberger, *The future of UAVs in ecology: an insider perspective from the Silicon Valley drone industry.* Journal of Unmanned Vehicle Systems, 2016.

9. Dale, D.R., *Automated Ground Maintenance and Health Management for Autonomous Unmanned Aerial Vehicles.* 2007.

10. Koji A. O. Suzuki, P.K.F., James R. Morrison, *Automatic Battery Replacement System for UAVs: Analysis and Design.* 2011.

11. *Gumstix.* 2006.

12. Glikin, I., *Choosing the Best Lead Screw for a Linear Motion Application.* Machine Design, 2009.

13. Eitel, L., *What are Lead Screws? Technical Summary for Motion Engineers.* 2011.

14. *Working or Operating Principle of DC Motor.*

15. Benson, C., *How Do I Interpret DC Motor Specifications?* 2012.

16. Schneider, B., *A Guide to Understanding LiPo Batteries.* 2012.

17. *Understanding LiPo Batteries.* 2017.

18. *Short Circuit - Causes and Effects.* Basic Electrical, Power system.

19. Lipsett, R., *Why Lead Screws are the Best Fit for Many Linear Motion Applications - and How to Rightly Apply Them.* Thomson Industris, Inc.

9. APPENDICES

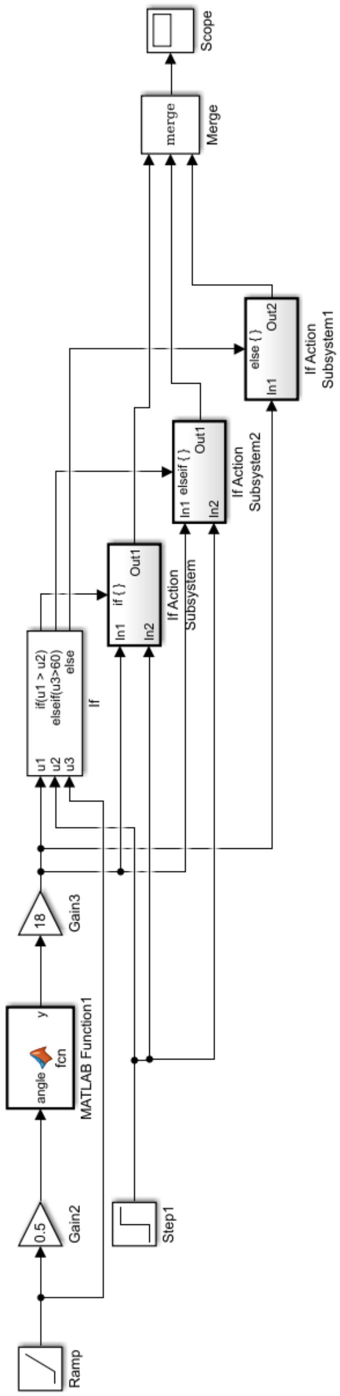

Figure 24: MATLAB Simulink block diagram for servo motor simulation.

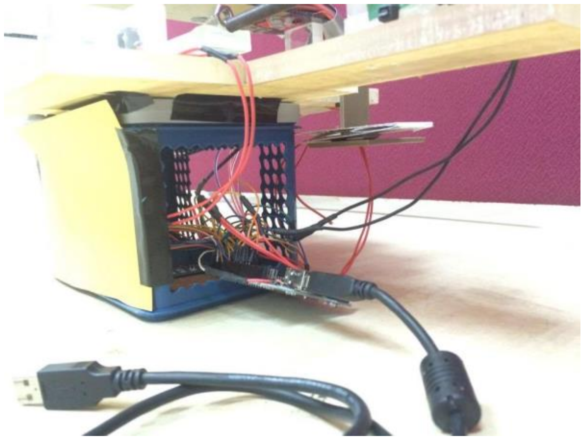

Figure 25: All the wiring connections and circuit boards are placed in a basket under the prototype platform.

```
const int buttonPin = 10;     // the number of the pushbutton pin
int count = 0;                // Count the button presses
int pull = 4;
int push = 5;
int pull1 = 6;
int push1 = 7;
int limitSwitch1 = 8;
int limitSwitch2 = 9;

// variables will change:
int buttonState = 0;          // variable for reading the pushbutton status
int x = 1;
void setup() {

  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);
  pinMode(pull, OUTPUT);
  pinMode(push, OUTPUT);
  pinMode(pull1, OUTPUT);
  pinMode(push1, OUTPUT);
  pinMode(limitSwitch1, INPUT);
  pinMode(limitSwitch2, INPUT);

  Serial.begin(9600);
  digitalWrite(pull, HIGH);
  digitalWrite(push, HIGH);
  digitalWrite(pull1, HIGH);
  digitalWrite(push1, HIGH);
}

void loop() {
  // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);
  int limitSwitchState1 = digitalRead(limitSwitch1);
  int limitSwitchState2 = digitalRead(limitSwitch2);
  Serial.println(limitSwitchState1);
  Serial.println(limitSwitchState2);

  // check if the pushbutton is pressed.
  // if it is, the buttonState is HIGH:
```

Figure 26a: Arduino programming codes.

```
  if (x == 1 && buttonState == HIGH ) {

    digitalWrite(pull, LOW);
    digitalWrite(push, HIGH);
    digitalWrite(pull1, HIGH);
    digitalWrite(push1, LOW);
    delay(20);
    if (limitSwitchState1 == HIGH && limitSwitchState2 == LOW ) {
      digitalWrite(pull, HIGH);
      digitalWrite(push, HIGH);
      digitalWrite(pull1, HIGH);
      digitalWrite(push1, HIGH);
      delay(5000);
      x = 2;
    }
  }
  if (x == 2 && buttonState == HIGH) {
    digitalWrite(pull, HIGH);
    digitalWrite(push, LOW);
    digitalWrite(pull1, LOW);
    digitalWrite(push1, HIGH);
    delay(20);
    if (limitSwitchState1 == LOW && limitSwitchState2 == HIGH ) {
      digitalWrite(pull, HIGH);
      digitalWrite(push, HIGH);
      digitalWrite(pull1, HIGH);
      digitalWrite(push1, HIGH);
      delay(5000);
      x = 1;
    }

  }
  if (buttonState == LOW){
      digitalWrite(pull, HIGH);
      digitalWrite(push, HIGH);
      digitalWrite(pull1, HIGH);
      digitalWrite(push1, HIGH);
  }
}
```

Figure 26b: Arduino programming codes.

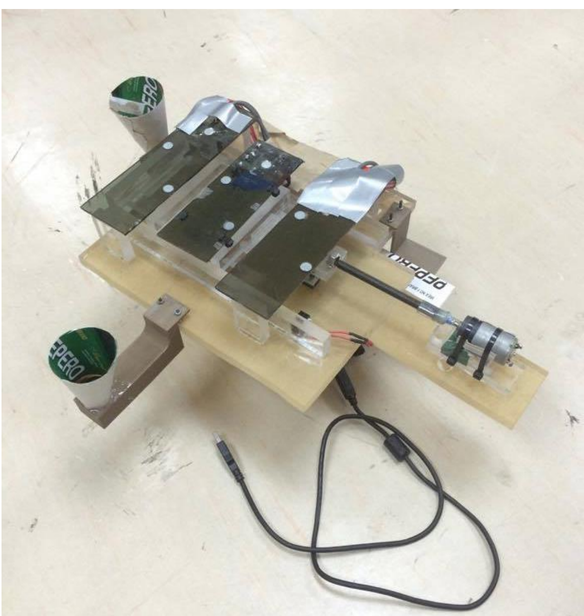

Figure 27: Isometric view of the prototype.

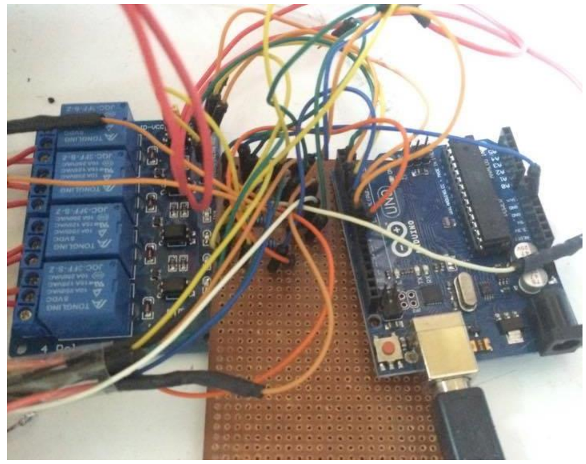

Figure 28: The wires are connected by soldering them on a circuit board.

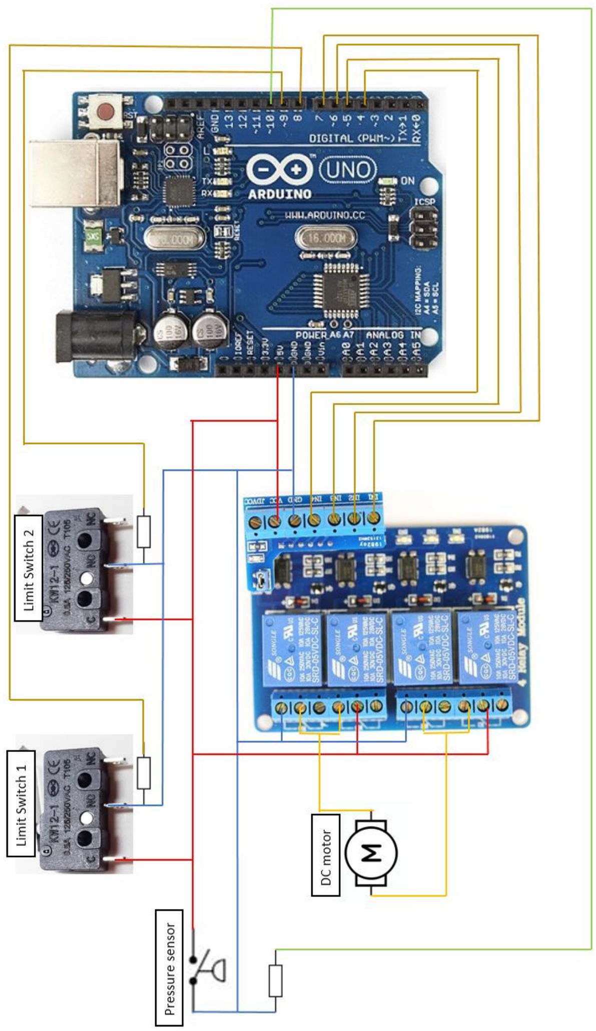

Figure 29: Circuit connection of the battery replacement system.