CONTROL OF 3D PRINTER USING DRONE WITH AUTOPILOT AND RASPBERRY PI MICROCONTROLLER

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “Control of 3D printer using drone with autopilot and Raspberry Pi microcontroller”. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or University.

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Date : 29 May 2019

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LIST OF ABBREVATION

3D	3 Dimensional
CAD	Computer Aided Design
UAVs	Unmanned Aerial Vehicles
STL	Stereolithography
GPS	Global Positioning System
SLA	Stereolithography
FDM	Fused Deposition Modelling
SLS	Selective Laser Sintering
LOM	Laminated Object Manufacturing
DLP	Digital Light Processing
G20	Greedy Two Opt
GA	Greedy Annealing
PEEK	Polyether-Ether-Ketone
ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactic Acid
V_x	Printing Speed
V_a	Extrusion Speed
D	Diameter PEEK Rod
d’	Diameter of The Extruded Filament
IT	Information Technology
IR	Infrared Ray
IMU	Inertia Measurement Unit
ADC	Analog-Digital Converter
I2C	Inter-Integrated Circuit
UART	Universal Asynchronous Receiver-Transmitter
RC	Remote Control
I/O	Input/Output

PPM	Pulse Position Modulation
PWM	Pulse Width Modulation
SBUS	Serial Bus
SD	Secure Digital
GPIO	General Pin Input Output
RPI	Raspberry Pi
SSID	Server Set Identifier
SSH	Secure Shell
IP	Internet Protocol
GCS	Ground Control Station
APM	ArduPilot Mega
UDP	User Datagram Protocol
TCP	Transmission Control Protocol
COM	Communication
USB	Universal Serial Bus
WP	Way Point
Lat	Latitude
Long	Longitude
AHR	Attitude and Heading Reference
EKF	Extended Kalman Filter
CMD	Command

ABSTRAK

Pencetakan 3D merupakan teknologi canggih dalam bidang pembuatan dan ia semakin popular di banyak bidang. Walau bagaimanapun, teknologi ini terbatas kepada saiz pencetak yang terhad. Kajian ini memberi tumpuan kepada penggabungan teknologi drone dan pencetakan 3D. Pencetak 3D boleh dikawal dengan menggunakan drone yang dipasang dengan autopilot dan mikro-pengawal. Oleh itu, produk boleh dihasilkan tanpa mempertimbangkan saiz pencetak. Laluan penerbangan boleh disimulasi dengan Mission Planner. Dua laluan penerbangan dengan saiz (2m × 8m) dan (20m × 80m) telah dihasilkan untuk mencetak lapisan berbentuk segi empat. Laluan penerbangan dengan saiz (2m × 8m) menunjukan hasil similasi yang lebih baik daripada laluan penerbangan dengan saiz (20m × 80m). Resolusi sistem kedudukan global juga akan mempengaruhi ketepatan hasil. Kajian ini telah menunjukan pencapaian dalam bidang pencetakan 3D dengan penggabungan teknologi.

ABSTRACT

Rapid prototyping or 3D printing technology is the advanced manufacturing process and it is getting popular to many sectors of field. However, there are some limitation of this technology which is limited to the printer size. This study focuses on combining of drone technology and rapid prototyping technology. Therefore, control the 3D printer using drone that paired with autopilot and microcontroller can build an object without considering the size of printer. The conversion of tool path to the flight path is done. Two flight paths for printing a rectangular sheet with size of 2m×8m and 20m×80m are generated. The simulation results show the flight path with size of 2m×8m is better than flight path with size of 20m×80m. However, this is concern to the resolution of global positioning system. This paper has made a big step toward the idea of combining the 2 technologies.

CHAPTER 1

INTRODUCTION

1.1 Research Background

The first 3dimensional (3D) printer was invented in 1981[1] and throughout the most decades, 3-D printing has been developing aggressively and it is believed that it will give another industrial revolution, in a general sense changing the way products are made. At the engineering sector, 3-D printing permits the efficient manufacture of geometrically and functionally complex products within a single process step, which provides tremendous chance to effective product design, custom products and rapid innovation in the product cycle. A lot of achievements have been made in especially in medicine, automotive or aerospace industry. Because of the open source systems, prototyping of new product, and innovative applications of 3D printing in different fields are accessible for everyone.

The working rule of 3D printing commonly can be accomplished by 3 phases which are modeling, printing and finishing. 3D printable models can be created with a computer aided design (CAD) or any other model generator software. Next, the 3D display must change over into STL document and being cut into a progression of slender layers and delivers G-code file. This G-code file can then be printed with 3D printing client software [2]. Finishing stage is required because of printing a marginally large than average variant of the ideal object in standard resolution, and after that expelling material with a higher-goals subtractive can accomplish a more prominent exactness [3].

Improvement of the printing material and 3D technology progressed toward becoming to be the objective for some organizations everywhere throughout the world from all industry parts. In 2014, genuine insurgency in development industry has begun, as the primary house was printed beginning another part in structure innovation. The pattern of utilizing 3D printing does not stop or deferral. 2017 has been an energizing year for the 3D printing industry, with a lot of new players showing up on the scene, just as innumerable new joint efforts and advancements. An improve thought of development 3D printing has turned out to be profoundly articulated in the present setting [4].

A mammoth 3D printer called KamerMaker was created to print the segments of house. Printing strategy is fundamentally the same as most of the 3D printers. Thermoplastic material is warmed by the printer until it achieves proper fluid state, so it tends to be set somewhere near a printer's spout. After one layer is made, another layer is based on the past one. In this phase of the procedure the most provoking thing to create is a material that after manufacture by the printer will be in the meantime sufficiently adaptable to make fitting layers, cement so the consequent layer will unite with the past one and solid enough, so the segment will safeguard its shape [4].

Construction 3D printing began with vast printers starting to print individual structure components and after that these components were assembled on a readied building site. In any case, these printers are expansive and bulky, have an entrance configuration, have restrains on the stature of the printed structure and are difficult to transport and assemble [5].

A drone, in a technological context, is an unmanned aircraft. Drones are all the more formally known as unmanned aerial vehicles (UAVs). Basically, a drone is a flying robot. The aircrafts are not operated by a pilot on-board [6] and can be remotely controlled or can fly autonomously through software-controlled flight plans in their embedded systems working in conjunction with onboard sensors and global positioning system (GPS).

In the recent past, UAVs were most often associated with the military, where they were used initially for anti-aircraft target practice, intelligence gathering and then, more controversially, as weapons platforms. Drones are now also used in a wide range of civilian roles ranging from search and rescue, surveillance, traffic monitoring, weather monitoring and firefighting to personal drones and business drone-based photography, as well as videography, agriculture and even delivery services.

Both 3D printing technology and UAV technology are the most popular technology in the recent. Hence the combination of these 2 technologies may bring a fresh scene toward the technology field. This research can utilize the UAV technology in order to solve the currently limitation of 3D technology which is printing limited size of objects. An ideal of control 3D printer using autopilot with drone was born due to its size and mobility. Autopilot with drone which controlled by the microcontroller will carry the 3D printer extruder and the tool path of printer will be converted to the flying path of the drone to print the object created by 3D computer-aided-design (CAD) model. The design will be fabricated and at the end of this project the performance of autopilot with drone and quality of the product printed will be study for further improvement in the future.

1.2 Problem Statement

Although there is giant 3D printer which can print large components like wall of house, but it is still have some limitations such as have limit on the size of printed object and inconvenience for mobility due to its generous size.

1.3 Objectives

- To fly the drone autonomously according to the flight path set
- To convert tool path of 3D printer to flight path of drone
- To control 3D printer by using drone with autopilot which paired with microcontroller

1.4 Scope Project

- Drone testing
- Wiring connection and writing algorithm for 3D printer extruder
- Conversion of tool path to the flight path
- Simulation
- Analysis of result

1.5 Thesis Organization

This thesis is organized into five chapters:

- Chapter 1 begins with a general background relating to 3D printing technology and drone technology.
- Chapter 2 briefly reviews the literature and provides useful insights reported pertaining to optimal parameters set for 3D printing, drone type and autopilot type that suitable for 3D printer application.

- Chapter 3 describe the technique used in this study to fly the drone and simulate the flight path which is converted from tool path based on G-code,
- Chapter 4 determine the failure and suitable condition for flight, and numerically analyze the displaced error of the simulated path with the desired path.
- Chapter 5 highlights the contributions of the thesis and provides recommendations for future investigations.

CHAPTER 2

LITERATURE REVIEW

2.1 3D Printing Process

3D printing or additive manufacturing is a process of making three-dimensional rigid object from a software data [7]. This innovation might probably alter development industry in not so distant future. For the most part, the 3D printing work process start with set up a model in a 3D demonstrating application. At that point it is sent out to a document in a typical 3D information trade position, STL (standard change language) which is the most widely recognized standard interface among CAD and fast prototyping (RP) frameworks. Next, The STL display is scientifically sliced by meeting it with level planes. Each slice represents to a cross-area information for the part. The layer thickness is the separation between these planes. This results a random segment order contour that are further processed to construct a continuous tool path [8].

2.1.1 Fused Deposition Modelling Technology

Different type of 3D printer utilizes unique sort of advancements, printing techniques and furthermore various types of materials. A portion of the 3D printing advances that are most comprehensively used nowadays are Stereolithography (SLA), Fused deposition modelling (FDM) Selective Laser Sintering (SLS), Laminated object manufacturing (LOM) and Digital Light Processing (DLP) etc. Fused Deposition Modelling technique manufacture a part layer by layer, from the base to the top as shown in Figure 2-1. Extruder heat and extrude thermoplastic filament based on the 3D information provided to 3D printer. The material solidifies straightaway after coming out from the extruder head and bond to the previous layer. FDM is a more affordable procedure contrasted with all other 3D printing strategy [9]. The low-cost advantage makes it suitable for ideal of combining 3D printing technology and drone technology.

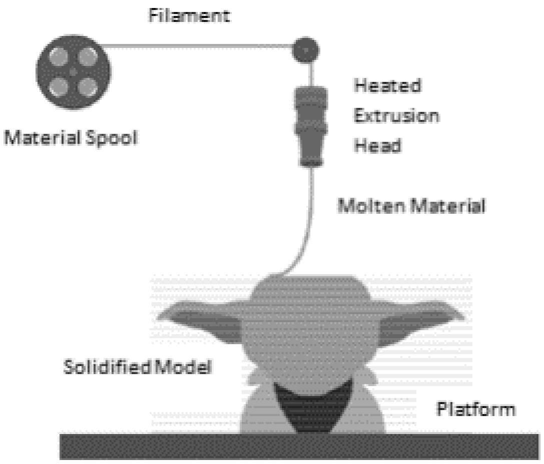
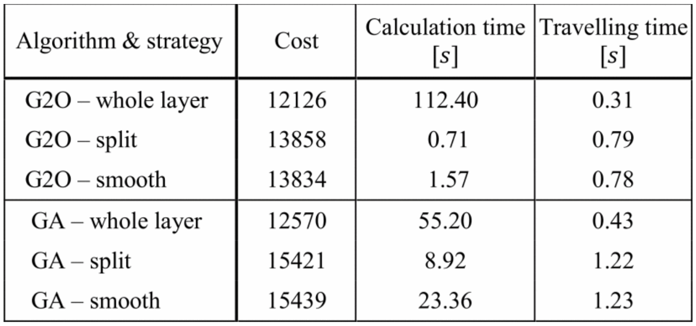


Figure 2-1: Fused Deposition Modelling process [9]

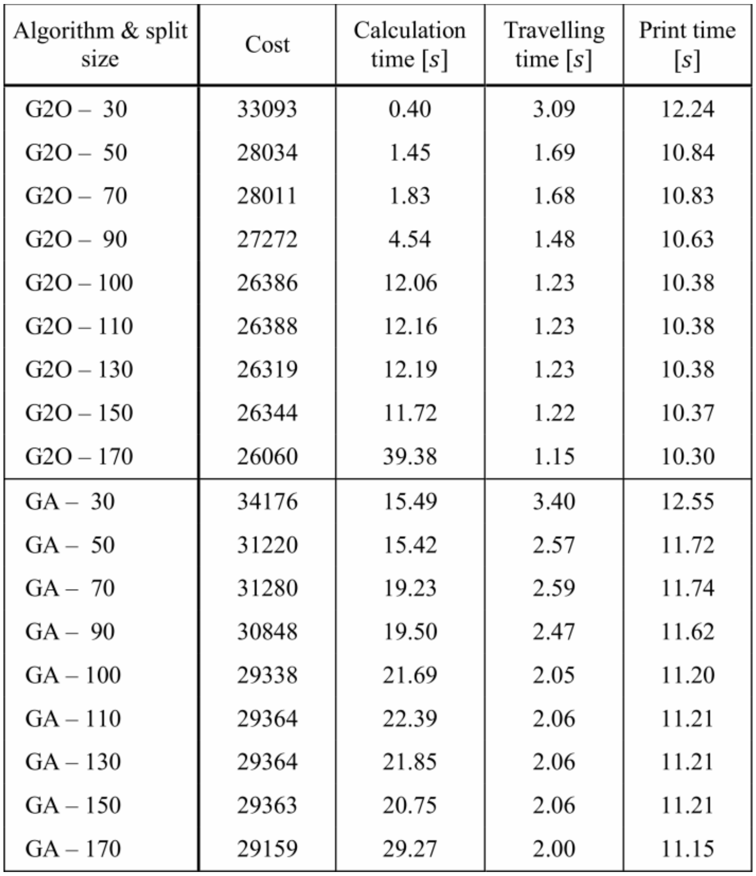
2.1.2 Algorithms of Path Planning for 3D Printing Process

For every one of the layers there is a path generated. The development of the printing extruder along the path is spared in extraordinary G-code file [10]. As indicated by the way that there are countless layers to print, the choice of path decides the general time required for printing an object. Therefore, reducing the length of paths becomes an essential part of the printing process [11] especially when the printing process is controlled by a drone which power is supplied by battery. There are 2 heuristic algorithms were engaged in the research to discover the capacity to decrease the all-out length of printing results in lower generally time required for printing process which are Greedy Two Opt (G20) and Greedy Annealing (GA). According to performed tests as shown in Table 2-1 and Table 2-2, G2O is faster and more accurate than GA. The splitting procedure highly increases time needed for calculation but decreases accuracy. However, its quickness can be used to calculate and produce layers concurrently. Smoothing process provides benefits, but with additional time spent on computations. Since points on the layer are densely located, the greedy part in G2O provides satisfactory results in quick time. However, there are some limitation of using greedy algorithms which they may not always reach the global optimum solution.



Algorithm & strategy	Cost	Calculation time $[s]$	Travelling time $[s]$
G2O – whole layer	12126	112.40	0.31
G2O – split	13858	0.71	0.79
G2O – smooth	13834	1.57	0.78
GA – whole layer	12570	55.20	0.43
GA – split	15421	8.92	1.22
GA – smooth	15439	23.36	1.23

Table 2-1: Performance of algorithms with different strategies [11].



Algorithm & split size	Cost	Calculation time $[s]$	Travelling time $[s]$	Print time $[s]$
G2O – 30	33093	0.40	3.09	12.24
G2O – 50	28034	1.45	1.69	10.84
G2O – 70	28011	1.83	1.68	10.83
G2O – 90	27272	4.54	1.48	10.63
G2O – 100	26386	12.06	1.23	10.38
G2O – 110	26388	12.16	1.23	10.38
G2O – 130	26319	12.19	1.23	10.38
G2O – 150	26344	11.72	1.22	10.37
G2O – 170	26060	39.38	1.15	10.30
GA – 30	34176	15.49	3.40	12.55
GA – 50	31220	15.42	2.57	11.72
GA – 70	31280	19.23	2.59	11.74
GA – 90	30848	19.50	2.47	11.62
GA – 100	29338	21.69	2.05	11.20
GA – 110	29364	22.39	2.06	11.21
GA – 130	29364	21.85	2.06	11.21
GA – 150	29363	20.75	2.06	11.21
GA – 170	29159	29.27	2.00	11.15

Table 2-2: Performance of algorithms for different sizes [11].

2.1.3 Extrusion Speed and Printing Speed on 3D Printing

The extrusion speed and printing speed on the 3D printing will affect the quality of the product [12]. From the studied paper, polyether-ether-ketone (PEEK) was used instead of the material such as acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) as 3D printing material. It reveals the relationship between extrusion parameters and the extruded filament morphology by free forming an extruded filament. Mass conservation concept is being used and the extrusion process is expressed as

$V_x / V_a = (D / d')^2$, （2.1）

Where V_x is the printing speed (or the nozzle velocity in the x/y direction), V_a is the extrusion speed (or the linear velocity of the PEEK rod pushed by the extrusion motor), D is the diameter of the PEEK rod and the d’ is diameter of the extruded filament. The extrusion speed was set in a range 0.1-120mm/min while the nozzle diameter varied from 407.96-621.52**µm**. The experiment begins with printing line and samples. From the result of the experiment, the best surface of the printed line at a printing speed of 335.45mm/min and extrusion speed of 80mm/min [13]. The present examination uncovered the instrument of expulsion and upgraded the printing exactness of PEEK FDM parts. However, the material such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) which are commonly used in experimental design shall be studied as well.

2.1.4 Temperature Setting for Extruding on 3D Printing

Temperature setting for extrusion will also affect the printing quality. The temperature setting is important as higher temperature will burn the material and lead to appearance of a residue in the hot-end and contamination of the remaining material [14]. On the other hand, lower temperature can cause unnecessary bonding between the deposited layers. An analysis on temperature setting for extruding material PLA was carried out. In the studied paper, finite element analysis is used to study the temperature distribution and the flow behavior of the PLA material. From the simulation, the temperature distributes from 178.29 ºC to 223.9 ºC along the hot end and the optimum temperature for extrusion of PLA is 190 ºC [15]. However, the studied is carried out by using simulation only, experiment shall be carried out to verify the simulation results.

2.2 Drone Technology

Unmanned Aerial Vehicles (UAVs) or drone are widely used as dedicated robotic platforms to illustrate and to test performance of new technologies. Drones are grouped by their shape, weight, working extent, speed and others. The most commonly way to classify the group is based on the shape of its wings. A UAV with wings fixed to its body, like a traveler plane or a military aircraft, is alluded to as a plane while for the drone that flies due to the rotation force of its wings, referred to as a copter or rotor. Currently, there are few sectors had implemented this technology which are defense sector, logistic sector, broadcasting sector, disaster prevention sector, IT sector etc. [16]

2.2.1 Waypoint Direction Finder Unit

In development of microcontroller system for UAV or drone, this report describes the basic function and application of microcontroller. It involves software development and hardware introduction. The waypoint direction finder unit is used to guide or steer the aircraft towards a preprogrammed waypoint or a route of waypoints. This is achieved partly with help of the onboard GPS. Every second the GPS sends "bearing", "heading" and direction to steer information as shown in Figure 2-2. This information is then used to calculate the difference in degree between heading and bearing. This result is then used to control the servo lever so that it matches with the bearing and decide the direction of servo lever. The waypoint finder unit integrate the GPS sensor, magnetic field sensor and accelerometer to work. There might had limitation for the number of waypoints that can be stored.

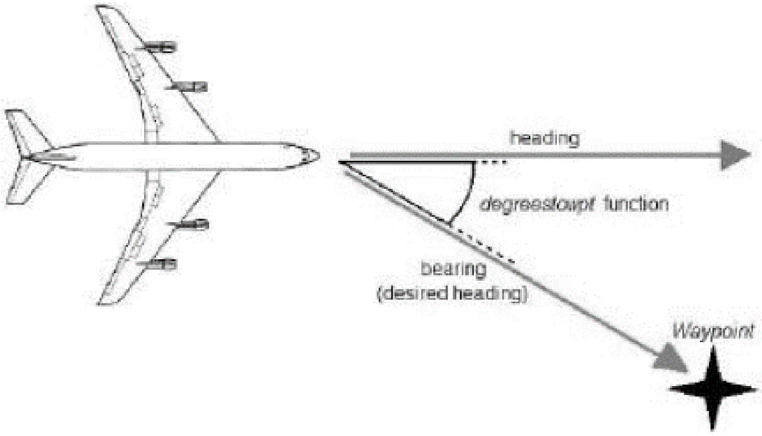


Figure 2-2: Navigation principle for waypoint direction finder unit [17]

2.2.2 Positioning Determination (Outdoor)

Positioning determination is very important especially when the 3D printing technology is added on the drone. GPS plays very important role in this case. The drone can be affected by many errors which come from different factors such as wind, solar weather, electromagnetic waves and the surrounding environment. All these considerations could influence the accuracy of UAV positioning. For UAV on board GPS, a total of 36 points were randomly distributed at the certain area and being observed. The observation is founded on single differencing between satellites as shown in Figure 2-3. The essential condition for differencing between satellites includes twelve parameters which are speed of light (c), orbital error (dρ), satellite clock error (dt), carrier wavelength (λ), ionospheric error (dion), troposheric error (dtrop), carrier phase measurement noise and multipath (εΦ), unknown integer cycle ambiguity (N), differences between pseudo range and carrier phase observation (λN), observed carrier phase (Φ), unknown satellite receiver range (ρ) and code measurement noise and multipath (ερ). The equation being used is as shown:

$⊿\rho = ⊿\rho + ⊿d\rho + c⊿dt + ⊿d_{ion} + ⊿d_{trop} + ⊿\varepsilon p$ （2.2）

$⊿\Phi = ⊿\rho + ⊿d\rho + c⊿dt + \lambda⊿N - ⊿d_{ion} + ⊿d_{trop} + ⊿\varepsilon\Phi$ （2.3）

$⊿\Phi = ⊿\rho + ⊿d\rho + c⊿dt - ⊿d_{ion} + ⊿d_{trop} + ⊿\varepsilon\Phi$ （2.4）

Where ⊿= denotes a single difference operator between satellites.

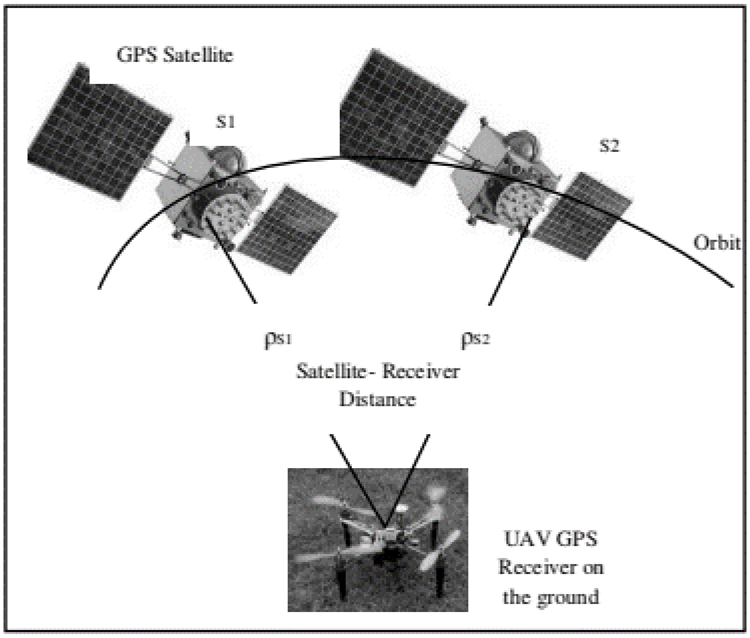


Figure 2-3: Differencing between satellites [18]

The results show that the range of latitude, longitude and altitude of UAV on board GPS were ±0.16 second, ±0.18 second and ±13.072 meters [18]. There are many types of onboard GPS and each of the type have different accuracy. Although the accuracy of this onboard GPS is considered high enough however, external GPS may contribute more accurately data compared to onboard GPS.

2.2.3 Positioning Determination (Indoor)

The development of autonomous drone platform requires real time information on location and motion of the vehicle. When GPS receiver is not functioning in indoor, motion capture systems can be used to provide additional measurements on position and on attitude of the vehicle. In this case, the vehicle is equipped by markers (IR source) to be tracked by IR sensors as shown in Figure 2-4. An acquisition system is then used to capture video frames from which a processing algorithm computes vehicle position and attitude by triangulation, knowing relative distances between markers [19].

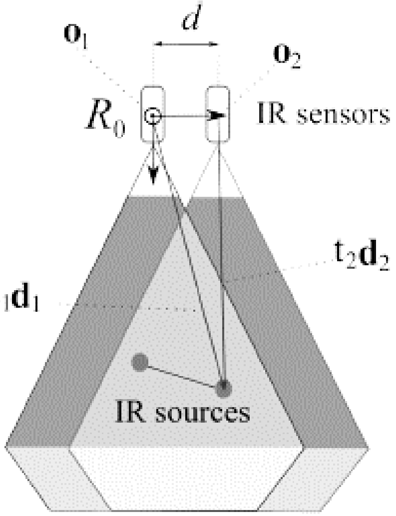


Figure 2-4: Tracking with 2 parallel IR sensors [19]

To maximize the area to be covered and thus increase the range of tracking, the location of IR sensors is important. The sensors may be rotated as shown in Figure 2-6 instead of parallel as shown in Figure 2-5. The area covered when the sensor be rotated by an angle can be calculated from the formula:

$$A_{\text{rotate}} = \frac{d^2(\tan(\alpha+\sigma)-\tan(\alpha))^2}{4(\tan(\alpha+\sigma)+\tan(\alpha))} \qquad (2.5)$$

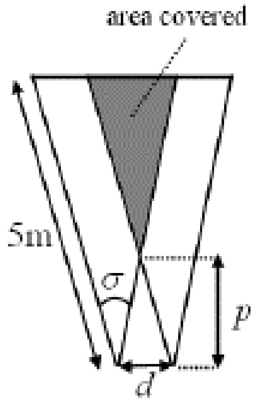


Figure 2-5: Parallel configuration [19]

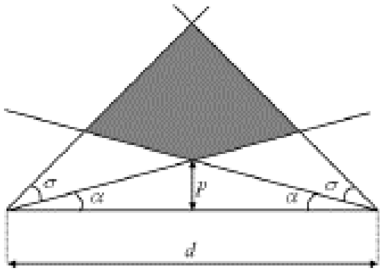


Figure 2-6: Rotated configuration [19]

The low-cost system for indoor motion tracking of UAVs is amazingly appropriate for further investigation in academic condition. Moreover, the accuracy is higher compared with the global positioning satellites system.

2.3 Drone Types That Are Suitable For 3D Printer Application

There are few of drones are available in the market which are multi-rotor, fixed wings, single rotor and fixed wing hybrid. Each of these drones have their own pros and cons [20]. 3D printing process is difficult task to handle by using a drone, so a normal drone is not suitable for this research. To execute the 3D printing application through a drone, the system should operate autonomously, provide extruder payload with low probability of failure and be able to operate more tactical mission. Hexa-copter is the only type of drone that suitable for 3D printing application as it meets those criteria [21]. Besides, hexa-copter has unique character such as more comfortable flight and less vibration [22] which are another important criterion required for 3D printer application.

2.4 Various Type of Autopilot Available

There is massive amount of autopilot brands in the market. Basically, autopilots are categorized into 3 flying style which are cinema flying, sport flying and autonomous flying. Cinema flying style is aim for purpose of obtaining smooth videos. Sport flying is aim for making quick changes in the flight of the device which are suitable for racing. Autonomous flying is able to do maximum work automatically [23]. To execute 3D printing application using drone, the autonomous flying style is more suitable in this research paper. The autopilot that suited with autonomous flying styles are included QWinOut APM, The 3DR Pixhawk and Navio2 etc.

CHAPTER 3

METHODOLOGY

3.1 Drone Selection

Type of drone is decided to use hexa-copter for 3D printer application after done the review. The drone being chosen must meet the criteria of payload that can support the weight of the 3D printer extruder. The extruder being used is describe in section 3.3 and the weight of the extruder is 0.53kg. Few types of hexa-copter drones are compared in term of price and the payload specification, DIJ F550 Flame Wheel as shown in Figure 3-1 is selected. The specification is shown as Table 3-1.

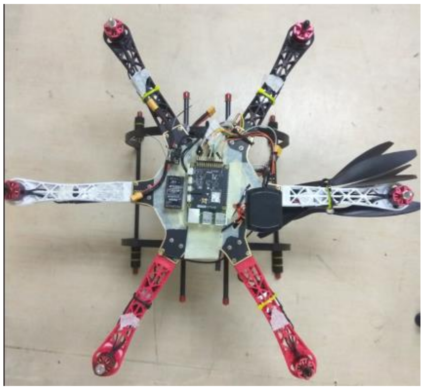


Figure 3-1: DIJ F550 Flame Wheel

Table 3-1: Specification of DIJ F550 Flame Wheel [24]

Weight	2kg
Max Carry Capacity	2.5kg
Max Velocity	43 miles per hour
Max Vary	Depend on the transmitter
Max Flight Time with Payload	20 minutes

3.2 Positioning Determination System Selection

Form the review section 2.2.2 and 2.2.3, there are two type of positioning determination system which are outdoor and indoor. The positioning determination for outdoor is based on usage of GPS which is an available source while indoor tracking system require extra cost and time to develop. To utilize the available source, positioning determination by using GPS is selected to use in this research paper.

3.3 Navio2 Autopilot

Autopilot is a system used to control the direction of drone without constant 'hand-on' control by human. Navio2 is being selected in this research as it is a utilized with the Raspberry Pi board. This autopilot isn't just structured as a stage for a Linux rendition of Ardupilot yet additionally as a stage for your custom mechanical activities such as executing 3D printing application. Besides, another reason of using Navio2 is it takes out any need various controllers locally available as everything is pressed into one (with the Raspberry Pi). Navio2 is equipped with double IMU, GPS/Glonass/Beidou receiver for accurate positioning and orientation, high resolution barometer (10cm), extension ports which included ADC, I2C and UART interface and RC I/O Co-processor which accepts PPM/SBUS input and provide 14 PWM output channels with variable frequencies. As everything is pressed into one, there is no extra components are required to install on the drone which will increase the weight and power to fly the drone. Navio2 with raspberry pi is shown as Figure 3-2.

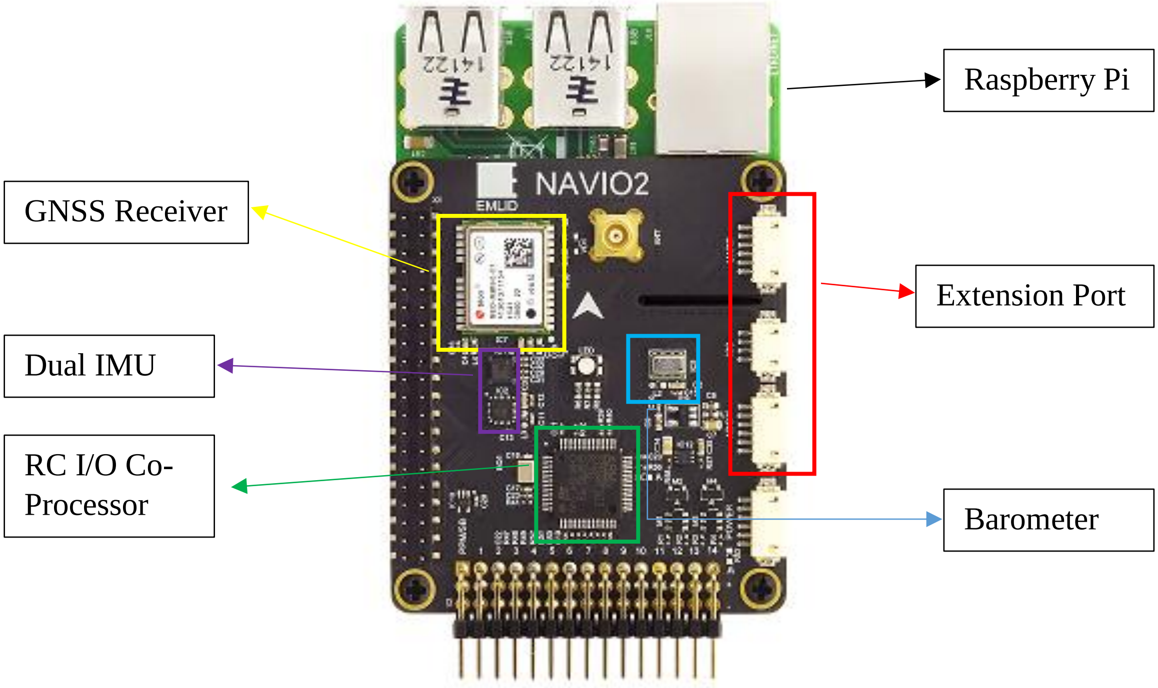


Figure 3-2: Components equipped with Navio2 Autopilot.

3.3.1 Raspberry Pi Configuration

Attached the Navio2 on the Raspberry Pi with extension header for 40-pin GPIO port and fixed them with screw. Next, write the Raspbian image into SD card by download and install the RPI firmware which is provided by Emlid. Download a software for writing images, a free software (Rufus Utility) was being used. Run Rufus with administrator right, then Tick "Create bootable disc" and select correct firmware and push Start and agree with all warnings. After that, configure the Wi-Fi network by editing the wpa_supplicant.conf file located on /boot partition. Enter the SSID and password for the wireless network that are going to work in. Then, find the IP address using an open source network discovery utility NMAP with Zenmap GUI. Look for the hostname “navio”. The last step is login and updates the system. Putty is used to login to Raspberry Pi with autopilot. In putty, SSH is selected for connection and the raspberry pi IP-address was typed in. In console login request will appear. Key in the identity and password and update the system by running:

```
sudo apt-get update && sudo apt-get dist-upgrade
```

The flow chart of raspberry pi configuration is shown as Figure 3-3.

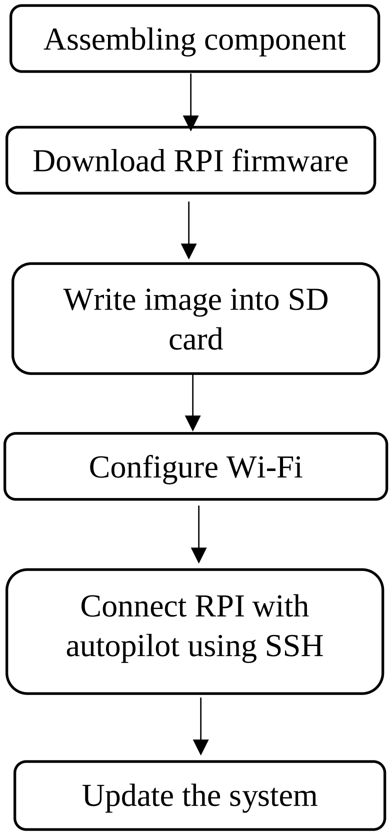


Figure 3-3: Flow chart for Raspberry Pi configuration.

3.3.2 Installation and Running

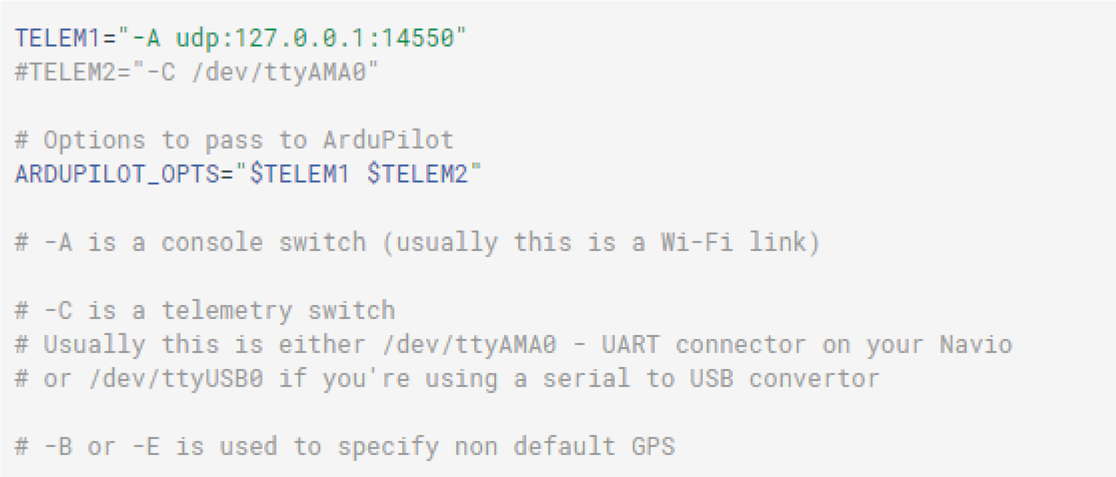
After ssh into raspberry pi, there will be a message to guide to select desired type of vehicle, version and board and also set the GCS IP address. Select the vehicle that would be launched by default with:

```
sudo emlidtool ardupilot
```

Arducopter is chosen as the drone using is hexacopter. Next, enable the copter on boot start the ardupilot and apply it. In this case, ardupilot will be configured. To specify the launching option, open the file with:

```
sudo nano /etc/default/arducopter
```

and specify the IP address of the ground station (laptop) by editing the “udp” as shown in Figure 3-4.



```
TELEM1="-A udp:127.0.0.1:14550"
#TELEM2="-C /dev/ttyAMA0"

# Options to pass to ArduPilot
ARDUPILOT_OPTS="$TELEM1 $TELEM2"

# -A is a console switch (usually this is a Wi-Fi link)

# -C is a telemetry switch
# Usually this is either /dev/ttyAMA0 - UART connector on your Navio
# or /dev/ttyUSB0 if you're using a serial to USB convertor

# -B or -E is used to specify non default GPS
```

Figure 3-4: Setting connection to ground station.

Run the Ardupilot by typing:

```
sudo systemctl start arducopter
```

and stop it using:

```
sudo systemctl stop arducopter
```

Last step in install autopilot called APM (Ardu Pilot) which can run directly on Raspberry Pi:

```
sudo apt-get install apm-navio
```

3.4 Ground Control Station (GCS)

GCS is a land- or sea-based control center that provide the facility for human control of drone. This software is typically used for planning and flying a mission. In this paper, “Mission Planner” is downloaded and used. There are some features of using Mission Planner:

- Point-and-click waypoint entry, using Google Maps
- Download mission log files and analyze them
- Configure APM settings for your airframe

3.4.1 Connect autopilot to GCS

After Launched the Mission Planner, connect the RPI with Navio2 to it by using:

```
sudo Arducopter-hexa -A udp:Ip-address :115200
```

115200 is for TCP port for Mission Planner and the IP-address is IP address of computer. If the connection is successful, top right side of the Mission Planner will as be shown as Figure 3-5.

UDP

115200

UDP-1-HEXAROTOR

Figure 3-5: Successful connection of autopilot with Mission Planner.

Another way to connect autopilot to GCS is using radio telemetry. The radio modem can be connected over UART port that available in Navio2 (as shown in Figure 3-6) while another modem connected over USB port in laptop. By using telemetry kit, the connection type is set to COM port number that assigned automatically and the connection rate is set to 57600 as shown in Figure 3-7. Telemetry connection is used during real flight test to avoid WIFI disconnected issues.

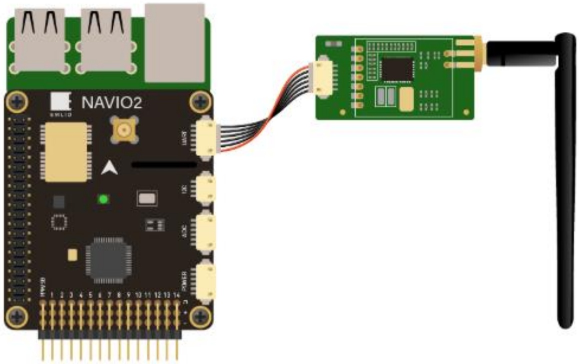


Figure 3-6: Connection of telemetry to Navio2

COM4

57600

Figure 3-7: Connection of autopilot with Mission Planner using telemetry kit

3.4.2 Calibration Hardware

To calibrate the drone, the frame class and the frame type parameter must be set to match the physical appearance of the drone being used. To calibrate the drone using Mission Planner, first go to initial setup > mandatory hardware > frame type and choose the type of the drone being used. In this paper, hexa-copter X as shown in Figure 3-8 is being selected.

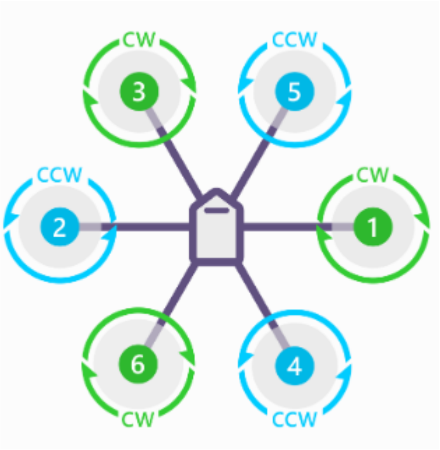
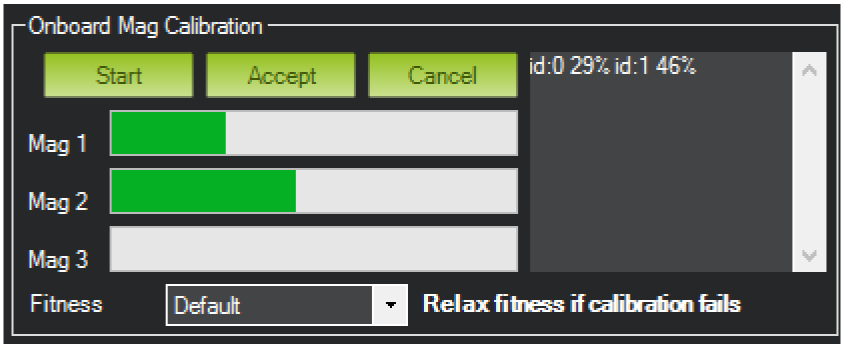


Figure 3-8: Hexa-copter X

Next is compass calibration. Under the mandatory hardware, select “Compass” and click the “Onboard Mag Calibration” section “Start” button. Then hold the autopilot in air and rotate it around which included front, back, right, left, top and bottom side. Rotate the autopilot until the green bar as shown in Figure 3-9 is filled completely.



id:0 29% id:1 46%

Figure 3-9: Compass Calibration

Then, radio control (RC) calibration is carried out. RC transmitter as shown in Figure 3-11 is used to control the drone movement and orientation which include throttle, pitch, roll, and yaw. To calibrate RC, first connect the receiver as shown in Figure 3-10 that support Pulse Position Modulation (PPM) and SBUS signal to the Navio2 and turn on the RC transmitter. Make sure the transmitter is bound to the receiver by the display of solid green light on the receiver.

Figure 3-10: RC receiver

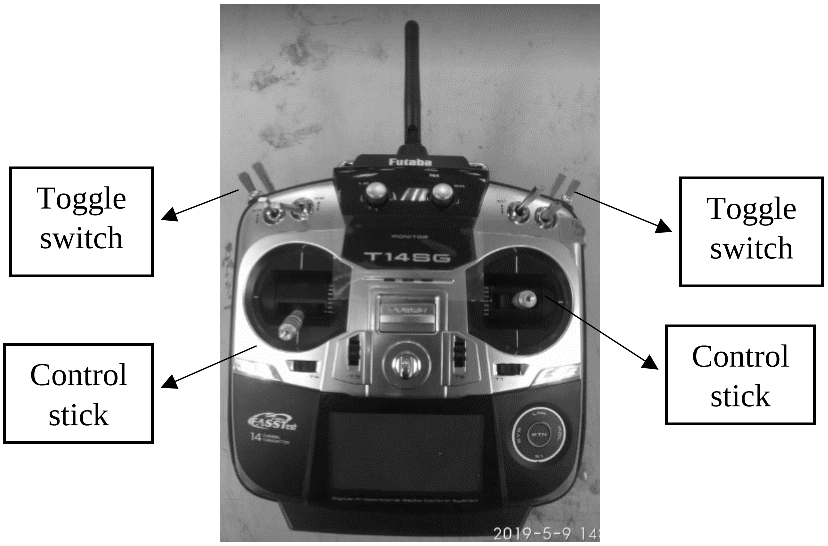
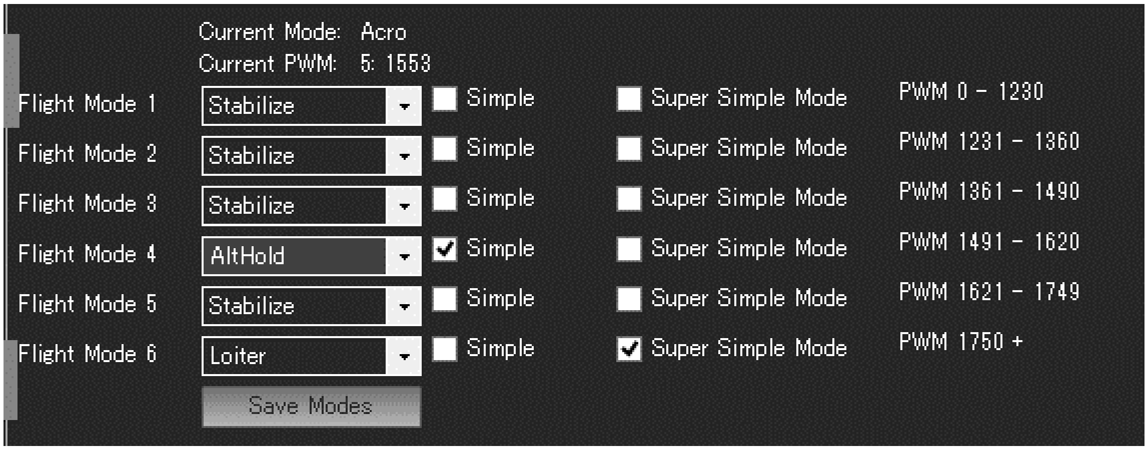


Figure 3-11: RC transmitter

Under the mandatory hardware, select “Radio Calibration”, click “Calibrate Radio” and move the control sticks and toggle switches on the transmitter until the limit of travel (indicate by red line on the calibration bars). Lastly, select “click when done” when all the required channels were calibrated. Flight mode configuration is required to change the mode to auto when running the mission planned. Go to “Flight Mode”, the screen will displace as shown in Figure 3-12, change flight mode 3 to “Loiter” while flight mode 6 to “Auto” for that switch position and saved it. Then test the transmitter switch by travel the toggle switch and see the changes of the flight mode.



Current Mode: Acro
Current PWM: 5: 1553

Flight Mode 1	Stabilize	☐ Simple	☐ Super Simple Mode	PWM 0 - 1230
Flight Mode 2	Stabilize	☐ Simple	☐ Super Simple Mode	PWM 1231 - 1360
Flight Mode 3	Stabilize	☐ Simple	☐ Super Simple Mode	PWM 1361 - 1490
Flight Mode 4	AltHold	☑ Simple	☐ Super Simple Mode	PWM 1491 - 1620
Flight Mode 5	Stabilize	☐ Simple	☐ Super Simple Mode	PWM 1621 - 1749
Flight Mode 6	Loiter	☐ Simple	☑ Super Simple Mode	PWM 1750 +

Figure 3-12: Flight mode configuration.

3.5 3D Printer Extruder

3D printer extruder is the part that feed the filament and eject material in liquid or semi-liquid form. In this paper, the model of filament extruder being used is MK8 Prusa i3 3D Printer Extruder 1.75mm filament as shown in Figure 3-13. The extruder consists of a stepper motor, cooling fan and a hot-end. The stepper motor is used to feed the filament while the hot-end is used to heat the material. The stepper motor will be control by a driver A4988 as shown in Figure 3-14 and controller (Raspberry Pi). The extruder will then be installed on the drone so that the printing process can be done following the flight path.

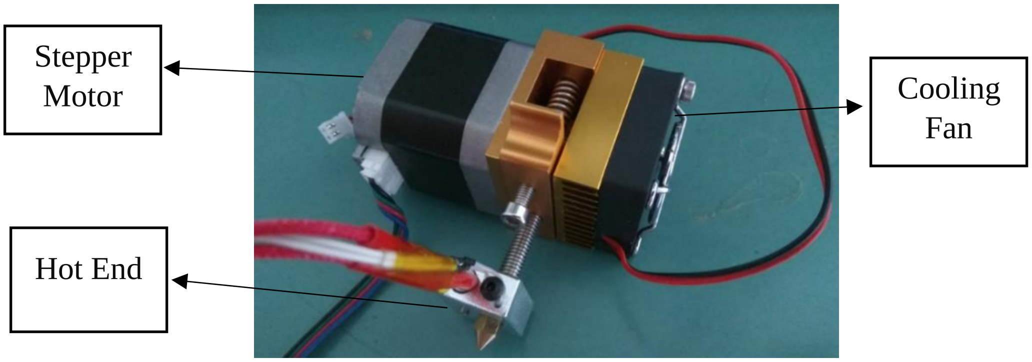


Figure 3-13: MK8 Prusa i3 3D Printer Extruder

Figure 3-14: A4988 Driver

3.5.1 Running of 3D Printer Extruder

To run the stepper motor properly, wiring connection must be done among the driver, microcontroller (Raspberry Pi) and the stepper motor. Since there are only left 2 GPIO pins available in the raspberry pi (all other pins were used up by Navio2), one of these pins can connected to step in the driver using male to female jumper wire through a breadboard. The connection is as shown in Figure 3-15. Since 3D printer extruder is only needing to feed the filament in 1 direction, therefore the pin used for control direction can be used for temperature controller.

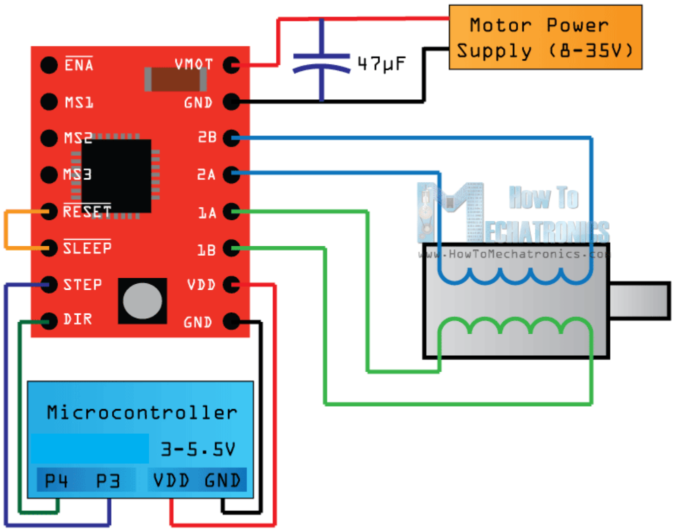
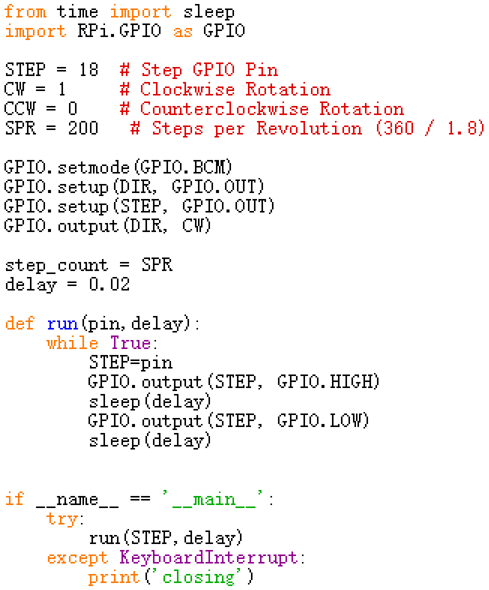


Figure 3-15: Wiring diagram of control stepper motor.

After the connection done, an algorithm is required to give command, so the stepper motor can run properly. The algorithm can be written in either C++ or Python language. In this paper, python language is being used. Hence, Python2.7 is installed and the algorithm is written in python script and saved as Motor.py file. Next, install WinScp (file-transfer application) to transfer the file from windows to the raspberry pi. One step of stepper motor is 1.8° which is equivalent to 200 steps per revolution. The algorithm give command to run the stepper motor continuously unless got interrupt by keyboard. The algorithm is as shown in Figure 3-16.



```
from time import sleep
import RPi.GPIO as GPIO

STEP = 18  # Step GPIO Pin
CW = 1     # Clockwise Rotation
CCW = 0    # Counterclockwise Rotation
SPR = 200   # Steps per Revolution (360 / 1.8)

GPIO.setmode(GPIO.BCM)
GPIO.setup(DIR, GPIO.OUT)
GPIO.setup(STEP, GPIO.OUT)
GPIO.output(DIR, CW)

step_count = SPR
delay = 0.02

def run(pin,delay):
    while True:
        STEP=pin
        GPIO.output(STEP, GPIO.HIGH)
        sleep(delay)
        GPIO.output(STEP, GPIO.LOW)
        sleep(delay)


if __name__ == '__main__':
    try:
        run(STEP,delay)
    except KeyboardInterrupt:
        print('closing')
```

Figure 3-16: Algorithm for running 3D Printer Extruder.