UAV Real-time Data Acquisition with Wireless Telemetry

Design File

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Role definitions:

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Title Page

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Contents

Executive Summary

Gyroscopic and pitot-static instruments are important in providing the pilot with flight-related information such as aircraft's current altitude, airspeed, and direction. These flight instruments are installed in the crewed aircraft's cockpit with layouts that depend on display technology and aircraft computer systems. These instruments vary from crewed aircraft, unmanned aerial vehicles (UAVs) or drones that can be remotely controlled and monitored from a distance or can be self-controlled by computers without a pilot on board. Drones use electronic devices for their operation such as microcontrollers, sensors, and actuators. Some of these electronic devices function like gyroscopic and pitot-static instruments on crewed aircraft. Therefore, data from sensors such as pressure, temperature and orientation can be processed through processors or onboard computers to give useful information to a ground-based crew that utilizes a monitor so that the flight can be managed from a distance. Onboard computers can transmit data and be commanded wirelessly via a radio frequency transceiver. The ground station receives the data and sends commands to the drones using a radio frequency transceiver of the same channel, frequency and transmission rate. The data acquisition, transmission and communication between drones and ground station have inspired the Octaltech Team to come up with the UAV Flight Instruments Project. The project will use sensors to obtain flight-related information which is then processed and transmitted wirelessly to ground-based telemetry.

Project Planning

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4. Project Management

4.2 Design File

This Design file has been compiled to outline the construction and development of UAV Data Acquisition system with Ground Telemetry by Octaltech Team. The project is to create sensor device for drones (e.g Mavic Pro DJI drone) that acts just like some of the flight instruments used in crewed aircraft. This device collects data on temperature, pressure, altitude, and drone orientation and then transmits these real-time data to ground-based telemetry. Another part in the final product is the ground-based telemetry. Commands and communication can be made wirelessly between drones and ground station via transceiver modules of same RF band. Examples of the commands from ground station to drone sensors are resetting altitude and calibrating drone orientation before drone takes off.

4.2.1 Specification Definition

The final product of the UAV Real-time Data Acquisition with Wireless Telemetry project must ensure the following requirements:

- Collect and process data from barometric sensor and inertial measurement unit.
- Effective transmission from drone-based transceiver to ground-based transceiver.
- Commands can be sent from ground station telemetry to drone sensors.
- RF transmission band and the operation of drone must be within legal frequency range established by Drone Rules from Australian Government.
- The circuits of final product must be well packaged in electronic enclosures.
- Data obtained from the sensors must be clearly monitor via telemetry within 100 radius.

4.2.2 Alternate Solutions

Solutions to the UAV Flight Instrument system apart from the UAV Real-time Data Acquisition with Wireless Telemetry are proposed as alternate solutions. Some of the solutions include:

- Pitot-static system: the solution uses pressure-sensitive instruments that is commonly used in aviation to determine aircraft's airspeed. The idea of the solution is to build a similar system that acts as the real pitot-static instruments and can function properly based on changes in pressure.
- Gyroscopic flight instruments: the solution has turn coordinator, heading indicator, and the attitude indicator which are often used in crewed aircraft. The solution is about building a system based on the principle of gyroscope and simulate the use of gyroscopic system in aviation.
- Turn coordinator based on sensor and actuator: the solution applies the use of inertial measurement unit or tilt sensor. The data from sensor drives the turnings of servo actuator which simulate the turn coordinator instrument used in aviation.

UAV Real-time Data Acquisition with Wireless Telemetry has been chosen by the project team with a number of conceptual ideas. These conceptual ideas were evaluated and ranked by members to find the most viable option.

4.2.3 Solution Selection

The principle and initial operation of the chosen solution to the project is examined by team members. Thus, the components are listed in order for the team to sketch the first general block diagram of the system. Design concepts are generated during the process and a number of different ideas regarding to the electronic devices, system operations and schematics.

Yet, the project team has decided to go with one final design concept after thorough evaluation and ratings based on several criteria including viability, availability of components, achievability, and legal specifications for drones established by Australian government.

4.2.3.1 General Block Diagram

From thorough consideration, the project team came up with the first general block diagram as shown below to approach the project.

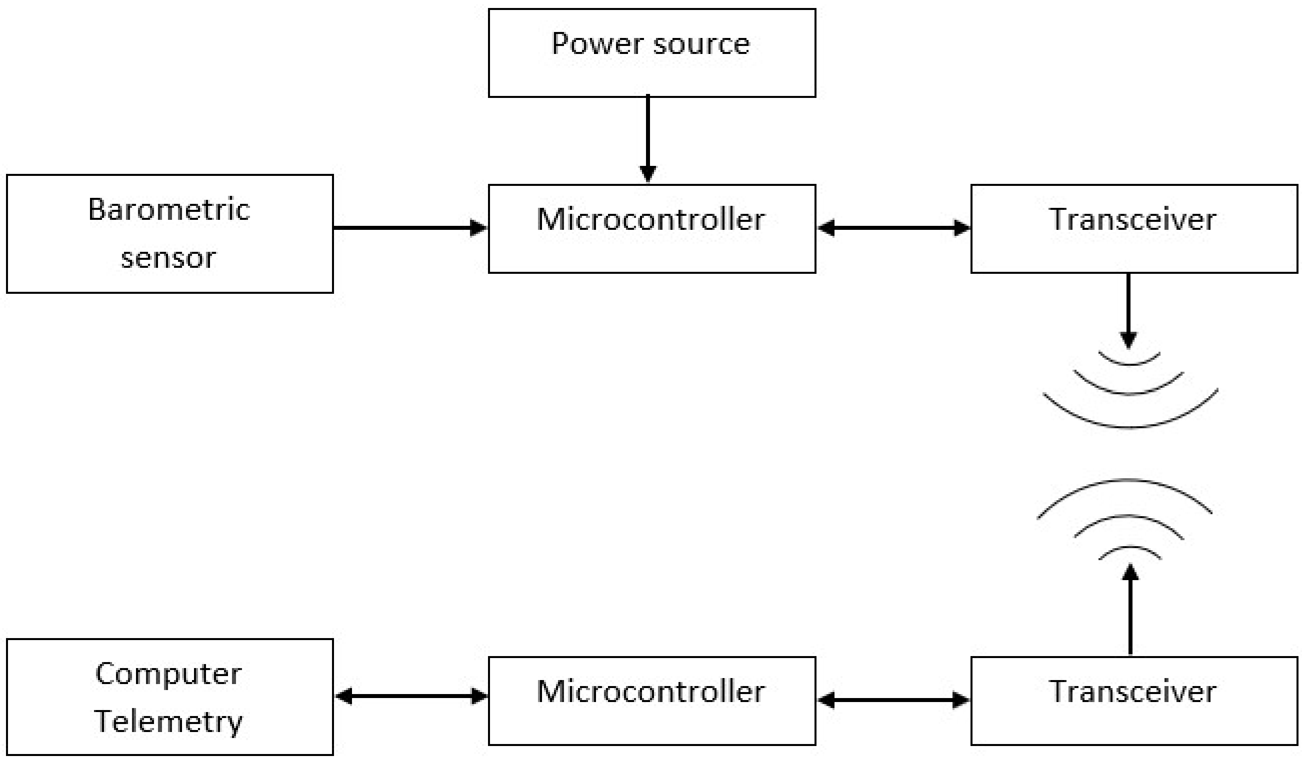

Figure 1: Simple block diagram for wireless data transmission between drone and ground station.

4.2.3.2 Descriptions of Components

The general uses of each electronic component shown in Fig. 1 is described below:

- Power source: is used to provide constant DC voltage to power the onboard microcontroller. The power source can be non-rechargeable batteries or rechargeable batteries. For the ground station, the microcontroller is powered via USB cable connected with computer telemetry. The ground-based microcontroller can also be powered using batteries.
- Barometric sensor: is used to collect temperature, pressure and even altitude data. These data are then fed to the microcontroller for processing.

- Microcontroller: for drone-based microcontroller, it is used to process data from sensor and then send processed encoded data to transceiver. For ground-based station, microcontroller receives data from drone sensors via ground transceiver. These received data is processed and decoded which is then fed to the computer telemetry for readable real-time information. The microcontroller is also be used to provide power to other components within the system.
- Computer telemetry: is used to show data on computer screen. The computer can also supply power to ground-based microcontroller via USB cable.
- Transceivers: carry operations that are transmitting and receiving data to and from microcontroller. Transceivers make wireless communication between drone and ground telemetry possible.

4.2.4 Conceptual Design

The conceptual design has been developed based on the general block diagram in Fig. 1. In the design diagram, specific modules for each component have been defined. The construction and further development of the project will be based on the operations and principles of these hardware.

The images below display the layout of the wiring and block diagrams of the ground telemetry and drone telemetry with specific hardware used in the project.

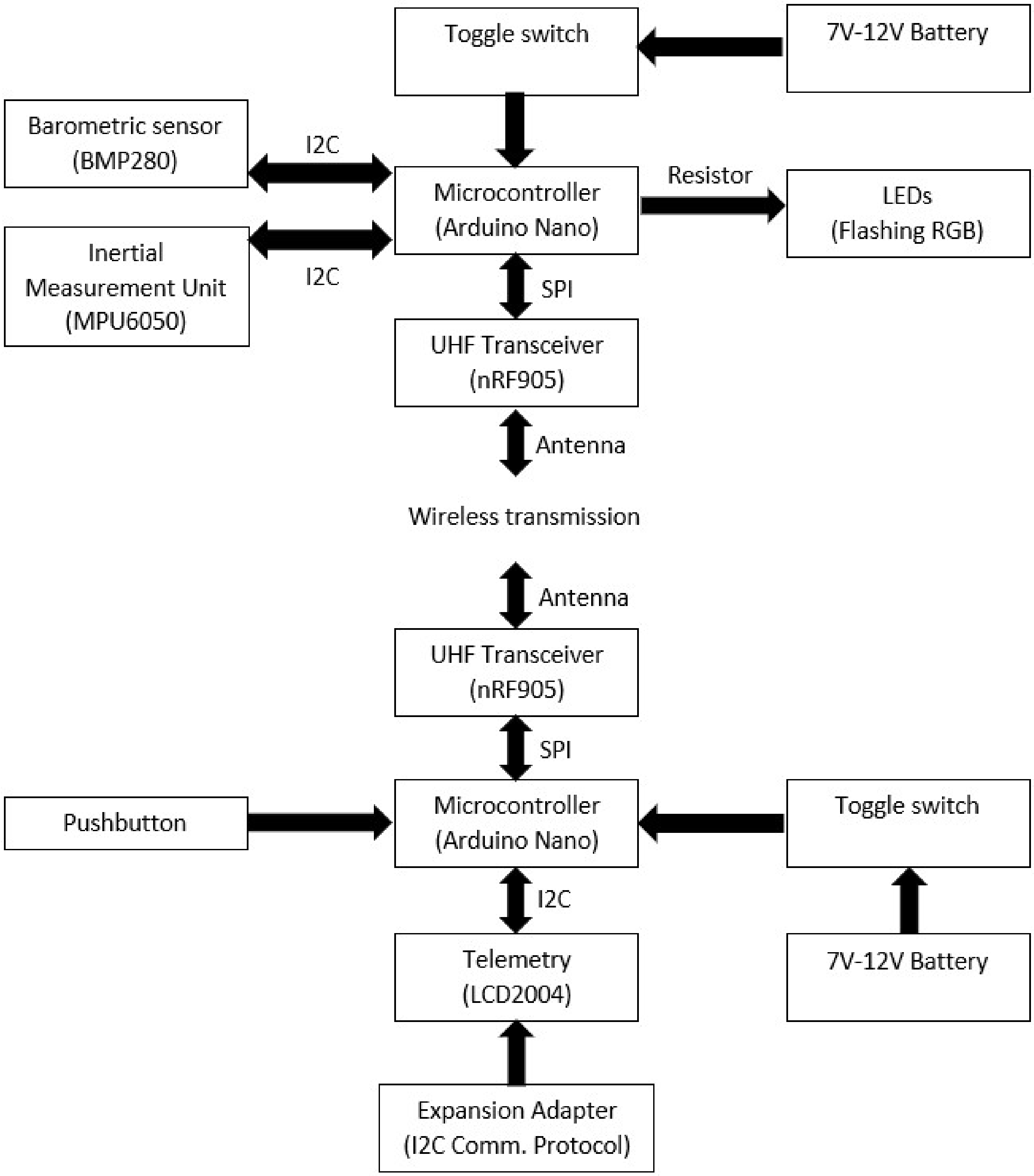

Figure 2: Detailed block diagram with specific component modules

4.2.5 Detailed Design

4.2.5.1 Circuit Schematics

Detailed circuit schematics are drawn using EasyEDA software to sketch the connection in order to reduce the wiring complexity and errors in the circuits.

4.2.5.1.1 Drone-based sensors

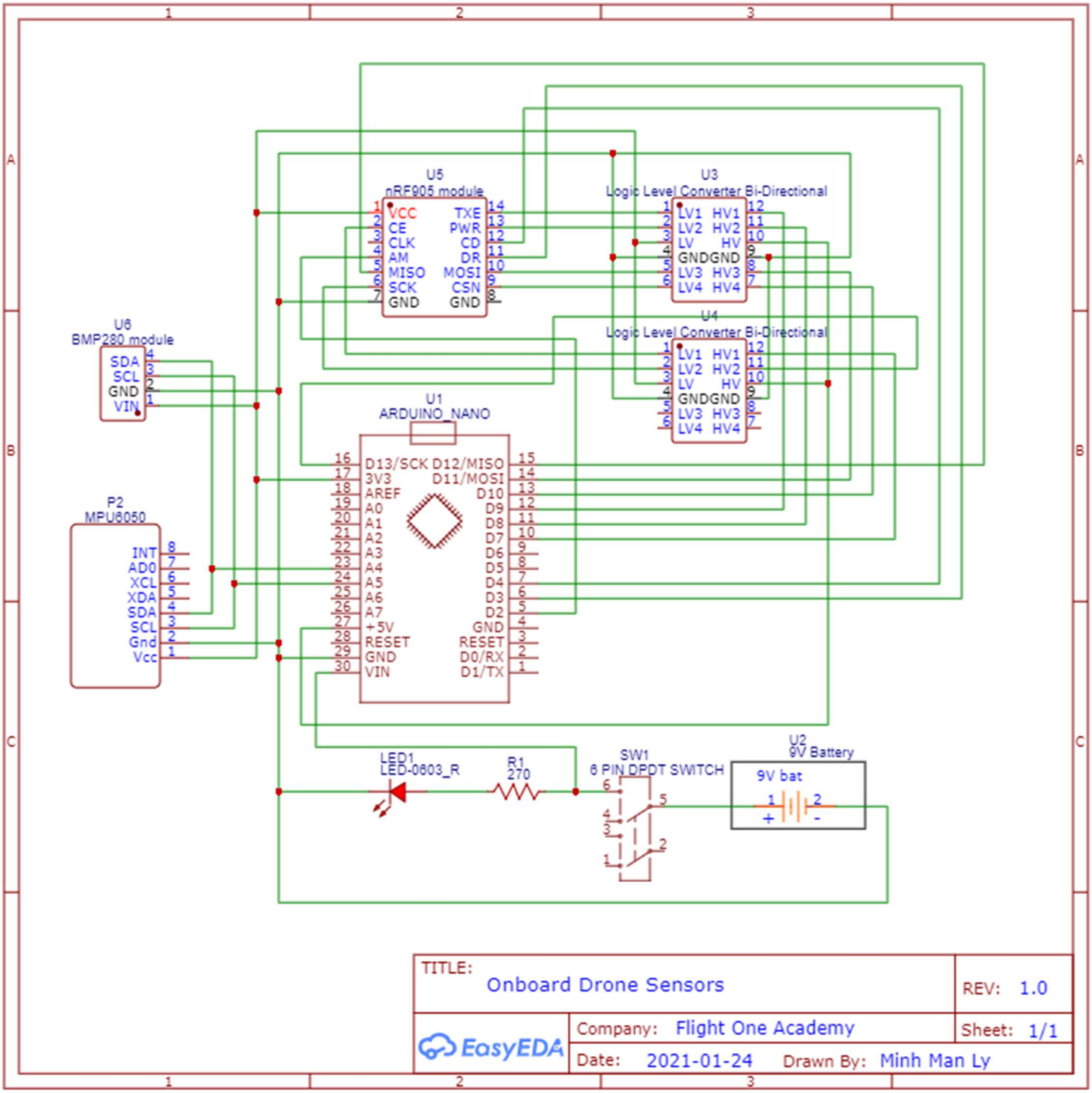

Figure 3: Circuit schematic for drone-based sensors

4.2.5.1.2 Ground-based Telemetry

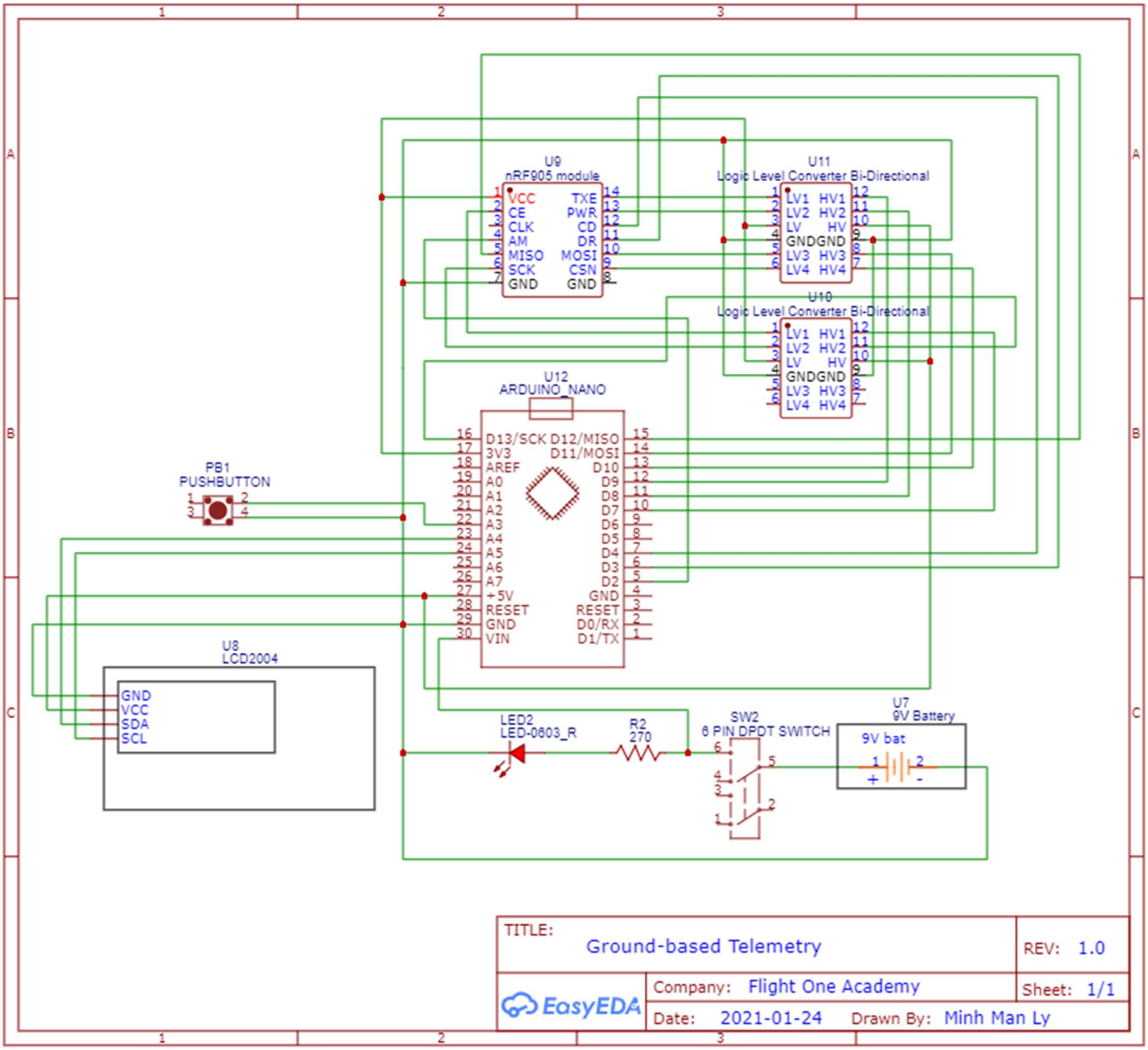

Figure 4: Circuit schematic for ground-based telemetry

4.2.5.2 Hardware and Software

Some main details on hardware are described below. Explanations are given on the reasons why these modules are used in the UAV Real-time Data Acquisition with Wireless Telemetry project.

Hardware is sourced from existing off-the-shelf components that the project team would use to create the UAV data collection and wireless transmission system. Free user software is utilised to control the systems operation.

4.2.5.2.1 Microcontroller – Arduino Nano

The Arduino Nano is a small and complete development board based on the ATmega328 microcontroller (for Arduino Nano with version 3.x). It works with a Mini-B USB cable to be programmed via Arduino IDE software.

Some noticeable technical specifications of the Arduino Nano include:

- Microcontroller: ATmega328
- Architecture: AVR
- Operating voltage: 5V
- Flash memory: 32kB of which 2KB is used by bootloader
- SRAM: 2KB
- Clock speed: 16MHz
- Analog input pins: 8
- EEPROM: 1KB
- DC Current per I/O Pins: 40 mA (I/O Pins)
- Input Voltage: 7-12 V
- Digital I/O Pins: 22 (6 of which are PWM)
- PWM Output: 6
- Power Consumption: 19 mA
- PCB Size: 18 x 45 mm
- Weight: 7 g [1]

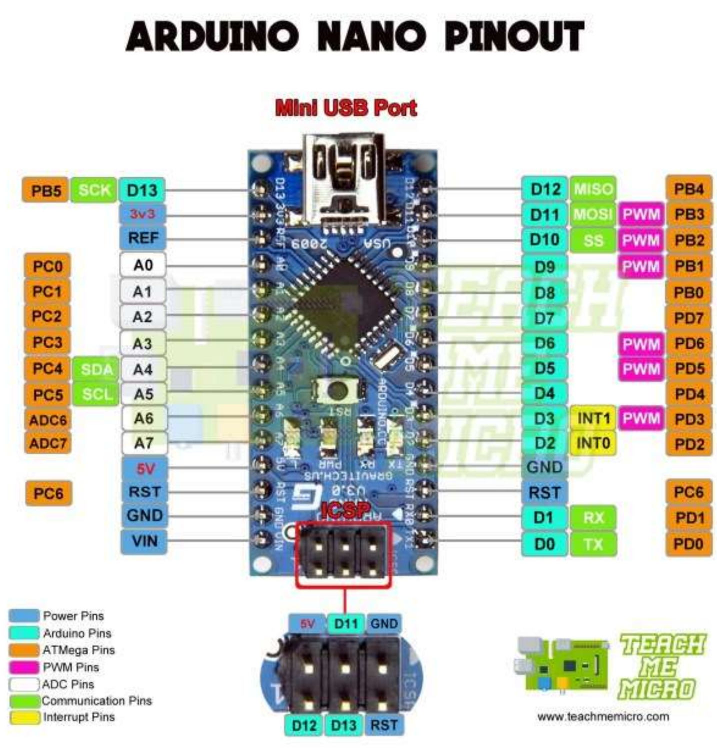

Figure 5: Diagram for pinout on the Arduino Nano [2]

4.2.5.2.2 Barometric Sensor – BMP280

The BMP280 is a absolute barometric pressure sensor, which is especially feasible for mobile applications. The BMP280 is based on Bosch's proven piezo-resistive pressure sensor technology featuring high accuracy and linearity as well as long-term stability and high EMC robustness. The device is optimized in terms of power consumption, resolution and filter performance.

Some noticeable technical specifications of the BMP280 include:

- Operation range Pressure: 300...1100 hPa
- Temperature: -40…85°C
- Absolute accuracy (Temp. @ 0…+65°C) : ~ ±1 hPa
- Relative accuracy p = 700…900hPa (Temp. @ +25...+40°C): ± 0.12 hPa (typical) equivalent to ±1 m
- Average typical current consumption (1 Hz data rate): 3.4 µA @ 1 Hz
- Absolute accuracy pressure (typ.) P=300 ...1100 hPa (T=0 ... 65 °C): ±0.50 hPa
- Relative accuracy pressure (typ.) P=900…1100 hPa (T=25…40°C): ±0.06 hPa (equivalent to ±50 cm)
- Average current consumption (1 Hz data refresh rate): 2.74 µA, typical (ultra-low power mode)
- Average current consumption in sleep mode: 0.1 µA
- Average measurement time: 5.5 msec (ultra-low power preset)
- Supply voltage VDDIO: 1.2 ... 3.6 V
- Supply voltage VDD: 1.71 ... 3.6 V
- Resolution of data:
  - Pressure: 0.01 hPa (< 10 cm)
  - Temperature: 0.01° C
- Temperature coefficient offset (+25°…+40°C @900hPa): 1.5 Pa/K, equiv. to 12.6 cm/K
- Interface (communication protocol): I^2C and SPI [3]

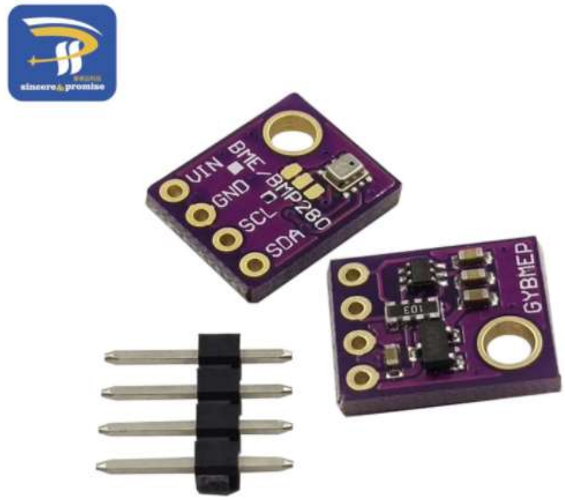

Figure 6: Barometric sensor - BMP280 [4]

4.2.5.2.3 Inertial Measurement Unit – MPU6050

The MPU6050 is a Micro Electro-Mechanical Systems (MEMS) which consists of a 3-axis Accelerometer and 3-axis Gyroscope inside it. This helps us to measure acceleration, velocity, orientation, displacement and many other motion related parameter of a system or object. This module also has a (DMP) Digital Motion Processor inside it which is powerful enough to perform complex calculation and thus free up the work for Microcontroller [5].

The module also has two auxiliary pins which can be used to interface external IIC modules like an magnetometer, however it is optional. Since the IIC address of the module is configurable more than one MPU6050 sensor can be interfaced to a Microcontroller using the AD0 pin [5].

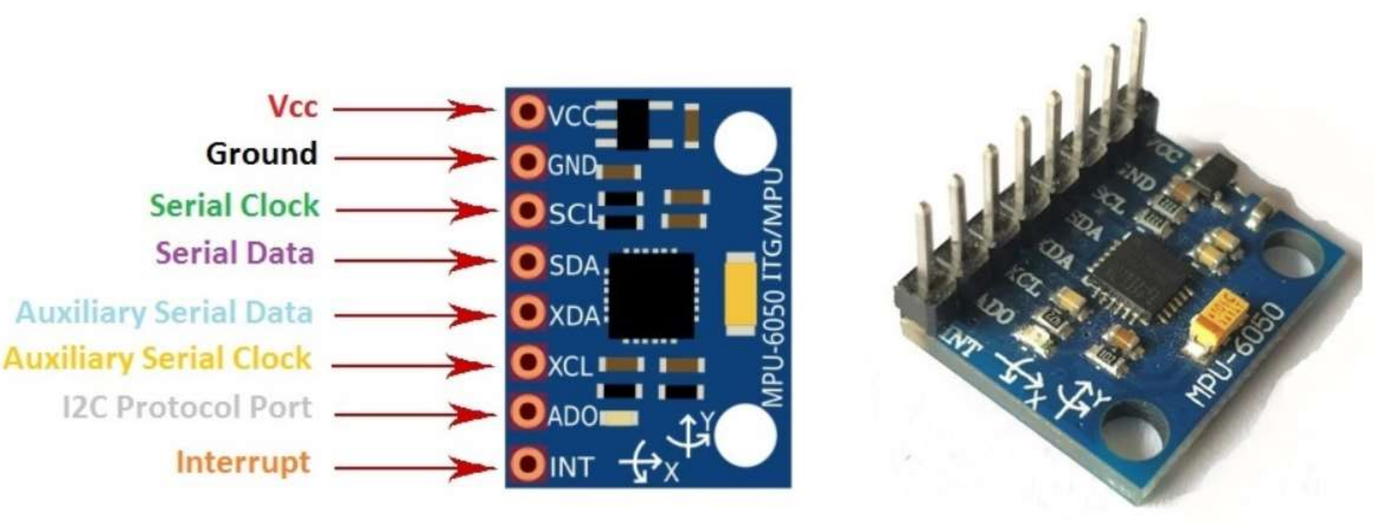

Figure 7: MPU6050 6-DOF gyroscope and accelerometer sensor module [6]

The MPU6050 has the following noticeable features:

- MEMS 3-axis accelerometer and 3-axis gyroscope values combined
- Power Supply: 3-5V
- Communication: I2C protocol
- Built-in 16-bit ADC provides high accuracy
- Built-in DMP provides high computational power
- Can be used to interface with other I2C devices like magnetometer
- Configurable IIC Address
- In-built Temperature sensor [5]

More details on the MPU6050's technical specifications can be found at [7]

4.2.5.2.4 UHF Transceiver – nRF905

The nRF905 is a small low cost, single chip, transceiver which can be used to send low bandwidth digital data. The nRF905 is similar to the well-known nRF24L01 but operates at 433/898/915MHz instead of 2.4GHz. However, the nRF905 data rate is only 50Kbps compared to nRF24L01's 2Mbps [8].

The project team decided to use nRF905 rather than nRF24L01 because the operating radio frequency range of the nRF24L01 is the same as the radio frequency of most quadcopter radio controller (RC controller) which is around 2.4GHz. This collision of same RF frequency band could potentially result in collapsed signals of the transceivers, and thus, data transmissions may fail.

The use of the nRF905's frequency band must be within the legal frequency band for ISM purposes established by Australian Government [9] [10].

Figure 8: nRF905 transceiver module with antenna [11]

The nRF905 uses SPI communication protocol which has 4 data lines. Those data lines are MOSI, MISO, SCK and CSN. In the project, the RF frequency band used for transmission between drone and ground station is 433MHz with 10dBm (10mW) maximum output power and sensitivity of -100dBm.

It is important to note that the nRF905 uses 3.3V logic. Directly connecting the nRF905 to the Arduino Nano microcontroller may result in damage since the Arduino Nano uses 5V logic. To ensure successful operation and to prevent potential for damage, a voltage divider or logic level converter is required on TXE, CE, PWR, SI, SCK, and CSN pins to level convert logic levels from 5V on the Arduino Nano to 3.3V on the nRF905 and vice versa [8].

Some noticeable technical specifications of the nRF905 include:

- Minimum supply voltage: 1.9V
- Maximum transmit output power: 10dBM (10mW)
- Transmitted data rate (Manchester-encoder embedded): 50-100kbps
- Supply current in transmit @ -10dBM output power: 11mA
- Supply current in receive mode: 12.5mA
- Temperature range: -40 to +85 *C
- Typical sensitivity: -100dBm
- Supply current in power down mode: 2.5uA [12]

More details on the nRF905 transceiver can be found at [12].

4.2.5.2.5 Bi-directional Logic Level Converter

Bi-directional logic level converter is a device that safely steps down 5V signals to 3.3V and steps up 3.3V to 5V at the same time. Because most Arduinos are 5V devices, and most modern sensors, displays, flash cards and modes are 3.3V-only, it is important to carry out level shifting/conversion to protect the 3.3V device from 5V. Although one can use resistors to make a divider, for high-speed transfers, the resistors can add a lot of slew and cause havoc that is tough to debug.

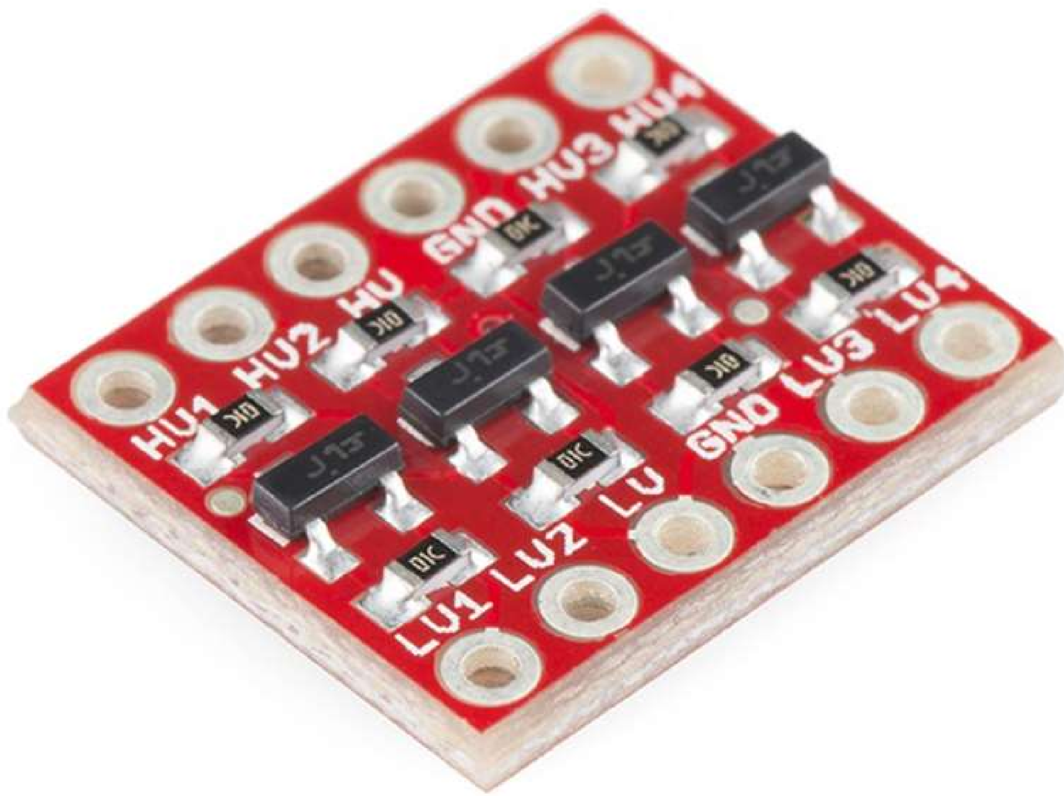

Figure 9: Bi-directional logic level converter [13].

4.2.5.2.6 Telemetry and I2C Expansion Adapter – LCD2004

The LCD2004 features four lines of 20 characters with backlight. The LCD2004 display module usually need the I2C expansion adapter for I2C communication protocol. The I2C expansion adapter also helps reduce wiring connection between Arduino Nano and LCD display.

The I2C communication protocol only uses 2 wires for serial communication which are SDA (serial data) and SCL (data clock).

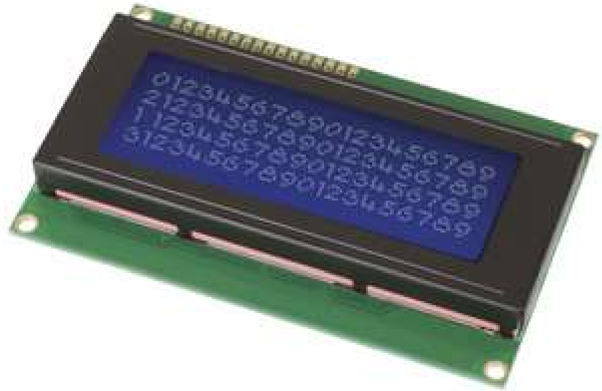

Figure 10: LCD2004 display with blue background [14].

Figure 11: I2C port expander module for LCD display [15].

4.2.5.2.7 Software

The software contributes to the completion of the project includes:

- Arduino IDE
- EasyEDA
- Autodesk Fusion 360 (education version)
- Multi-maker Cura slicer

Apart from those hardware and software mentioned above, 3D printer Prusa i3 MK3 is used to print the 3D enclosures for the project.

4.2.5.3 Program codes

The Integrated Development Environment (IDE) used to program the microcontroller – Arduino Nano is Arduino IDE which operates on C/C++ programming language.

4.2.5.3.1 Drone-based sensors

The completed Arduino Nano code for sensors on the drone is available at [16].

4.2.5.3.2 Ground-based Telemetry

The completed Arduino Nano code for ground station telemetry is available at [17].

4.2.5.4 Completed Circuit Boards

Completed circuits are soldered into PCB double sided prototype boards. Switches, buttons and battery snaps are also soldered to the circuit boards.

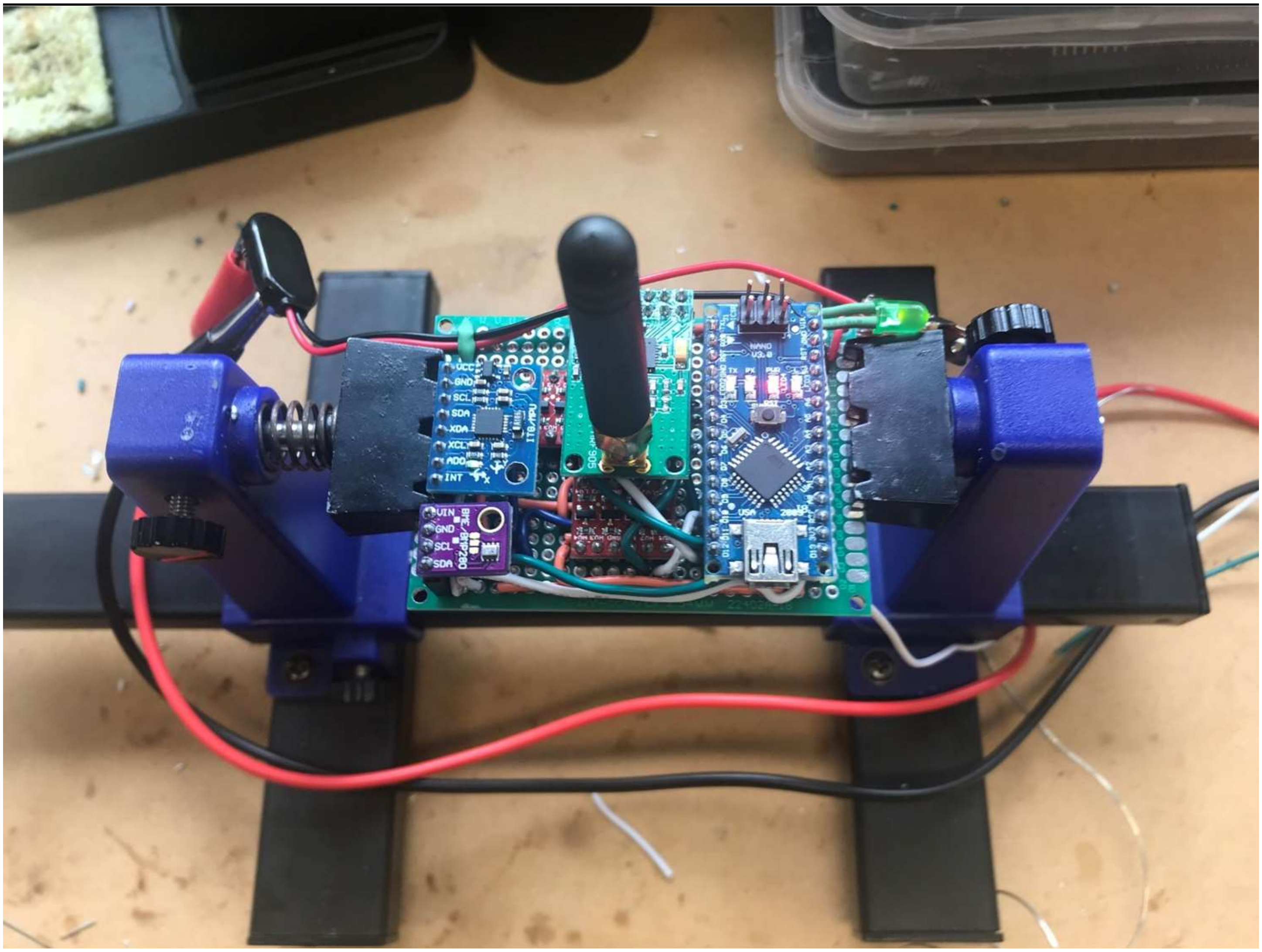

Figure 12: Circuit board for drone-based sensors during soldering process

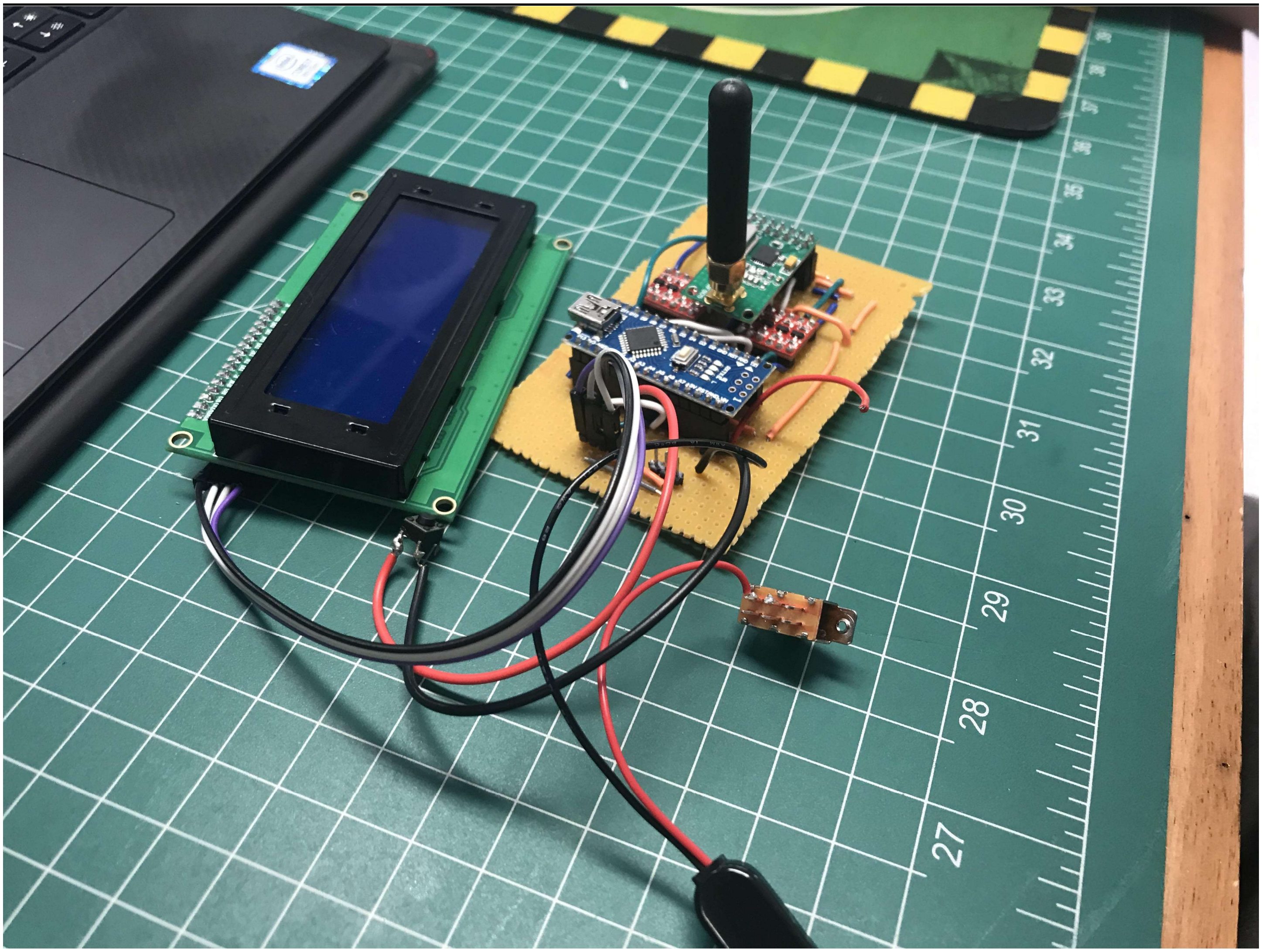

Figure 13: Completed circuit board for ground-based telemetry.

4.2.5.5 3D Enclosure Designs

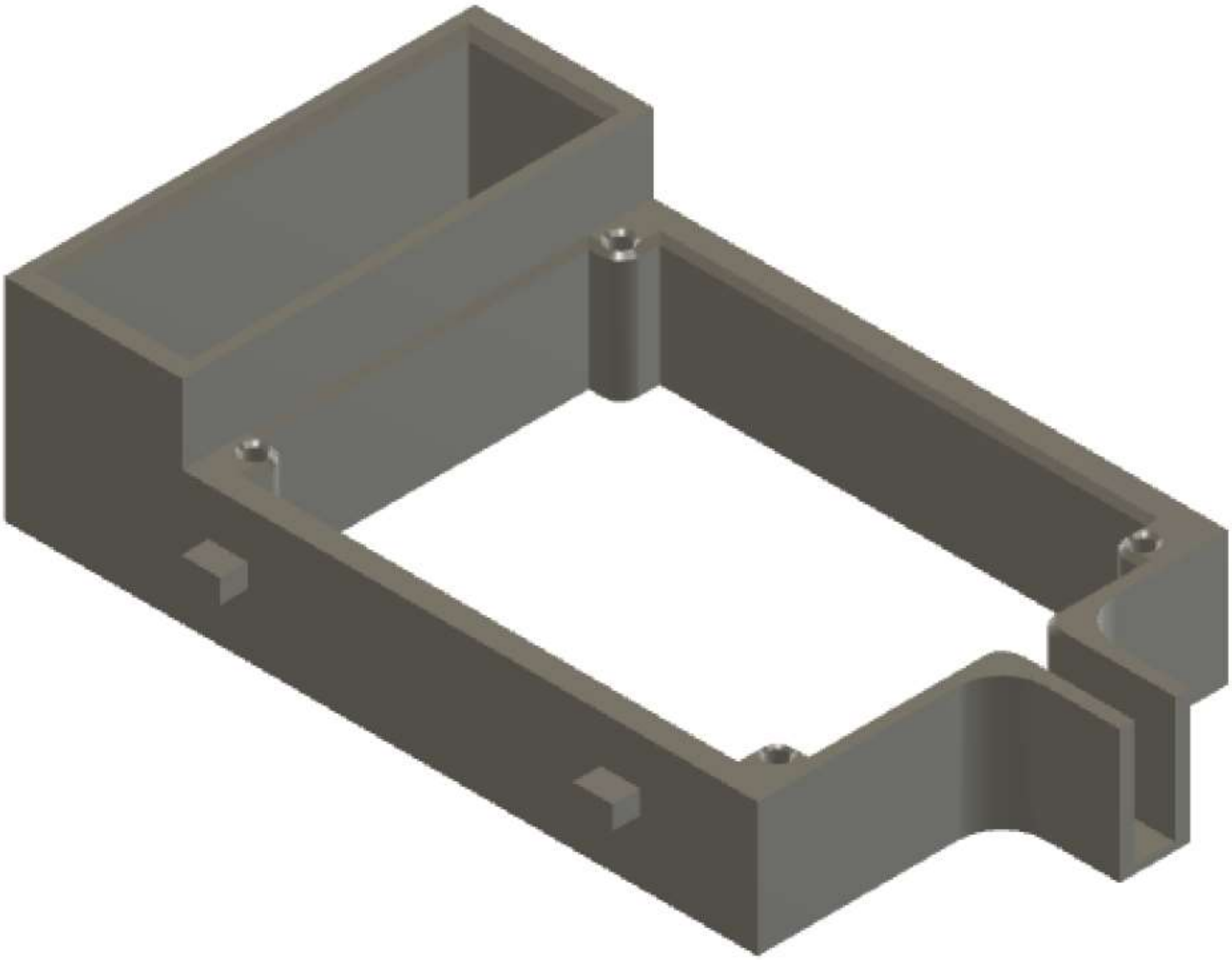

Figure 14: 3D electronic housing for the drone-based sensors, Arduino Nano and transceiver.

Fig. 14 shows the 3D printed holder for the drone-based circuit board. The on/off DPDT switch will be mounted out the front and the battery will be mounted in the rear.

Figure 15: 3D printed top cover for the drone-based circuit holder.

Fig. 15 shows the top cover for the drone-based circuit board holder in Fig. 14. It has a cut-out for the antenna and airflow holes to help act as a static port and allow the electronics to dissipate heat easier. This cover is designed to clip onto the Arduino holder and use Velcro straps to ensure a safe and effective package is created.

The top cover and Arduino holder create a drone backpack to house all the electronics whilst protecting the barometric pressure sensor from unrealistic measurements due to airflow from the drone motors.

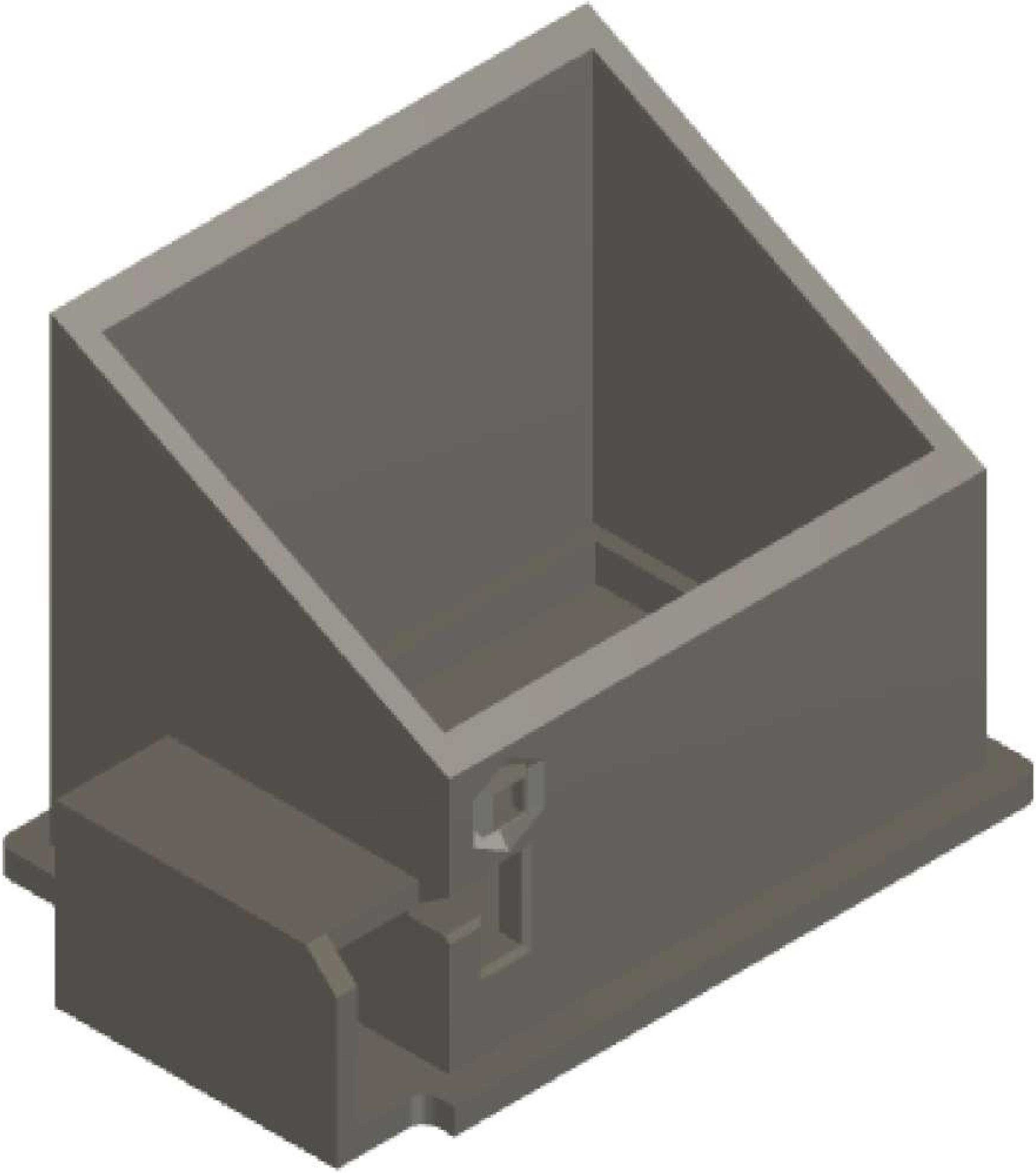

Figure 16: Ground-based station 3D case for LCD display and ground circuit board.

Fig. 16 shows the ground station case. This case features a spot to install a battery, on/off switch, and momentary switch. The large opening on top is filled by the 4x20 LCD screen with a laser cut acrylic sheet ensuring a tolerable fit that neatly stores all electronics keeping the wiring and micro controller safe.

4.2.5.6 Packaging

After the circuit boards have been done and fully tested. Dimensions of the circuit boards are measured in order for the team to design and model 3D enclosures for both circuits, the drone-based sensors and the ground-based telemetry. The completed circuits are packaged in 3D electronic enclosures that are specifically designed to be installed to DJI Mavic Pro quadcopter drone.

Software and machine used for 3D designing and printing include:

- Autodesk Fusion 360 (education version)
- Multi-maker Cura slicer software
- 3D printer Prusa i3 MK3

Figure 17: The packaging of drone-based circuit with specifically designed 3D enclosure.

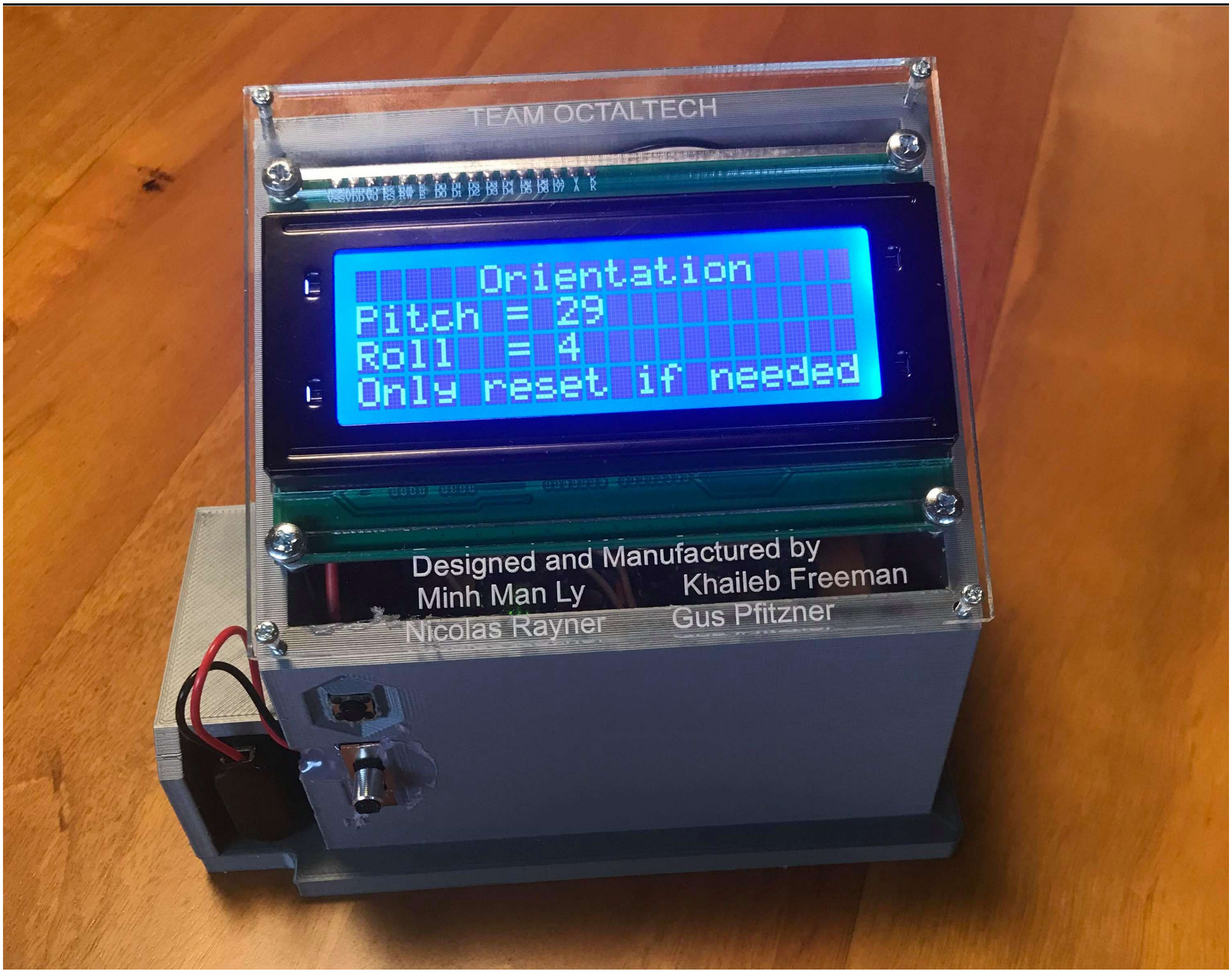

Figure 18: The packaging of ground-based telemetry with laser cut acrylic.

4.2.5.7 Operation Instruction

In order to turn on and successfully use the system, the following steps can be done:

- Turn on the switches for both the drone-based sensors and ground-based telemetry. The green LED on the drone-based circuit indicates the sensors have been turned on while the backlight on the LCD display indicates the telemetry is ready to receive data.
- If the drone-based sensors have not been turned on while the telemetry has been on, the LCD display will show "Waiting for data …" on the screen.
- If the transmission between two transceivers are successful, the telemetry will show the first page of the system that is the "TPA Reader" page which display temperature (*C), pressure (hPa) and altitude (m) from BMP280 sensor.
- To reset the ground altitude to 0m, stay on the "TPA Reader" page, then press and hold the button for more than 1.5 seconds. The LCD screen will show "Resetting altitude …" which indicates successful reset.
- Press the button (or press and hold for less than 1.5 seconds. From the "TPA Reader" page, the LCD screen will change to the "Orientation" page which display pitch and roll (in degree angles) of the drone from MPU6050 sensor.
- To reset the pitch and roll to 0 degrees, stay on the "Orientation" page, then press and hold the button for more than 1.5 seconds. The LCD screen will show "Resetting MPU6050 …" for a short moment and then escape to another page. That new page requires users to "Press the button". The reset of MPU6050 usually takes around 5 seconds to calibrate and stabilize.
- By pressing the button on the "Press the button" page, the LCD screen will go back to the "TPA Reader" page with barometric data.

If the LCD display freezes, stop receiving data or having weird data on the screen, simply reset the drone-based sensor by either press the reset button on the Arduino Nano microcontroller or turn off then turn on the whole drone-based sensors via switch.

4.2.5.8 Limitations and Technical Issues

The system has ensured some basic operations without problems while testings. Yet, there are several limitations or technical issues that affect the continuous and effective operation of the system.

Limitations:

- The maximum range for the transmission between two transceivers is around 30-40m.
- The higher the range, the slower the respond rate of the transceiver due to power output. Therefore, at maximum operating range, the pitch and roll data will show a latency from 500ms to 1000ms compared to only 200ms latency at shorter range.
- The maximum power output of transceiver is 10dBm (10mW) which is the legal RF frequency band for 433MHz allowed for ISM purposes in Australia [9] [10]. Therefore, 10mW output power is not ideal for operating at high distance (more than 100m).

- The capacity of battery will affect the operation of the system. The whole system requires 7-12V power source to operate at normal condition. Dropping this value down below 7V will not provide enough power for the sensors and transceivers to process according to their datasheets.

Technical issues:

- The I2C communication protocol is prone to noise which means it can pick up distortion. Thus, if the SDA and SCL wires connecting the Arduino Nano and sensors are disturbed, the sensors will give incorrect values and the LCD display will be frozen.
- The LCD display has a minor error where the page after the “Orientation” display is an empty screen, not the “TPA Reader” display. This error has been fixed by putting “Press the button” display to the LCD at this empty screen.
- The resetting of MPU6050 on the “Orientation” page is not smoothly operated. When the user reset MPU6050, the LCD screen will escape to the “Press the button” page. Then, if the user press the button, the LCD screen still shows “Press the button” for a few seconds before entering the “TPA Reader” page. This is because the MPU6050 needs more than 5 seconds to reset and the empty screen error after the “Orientation” page.

4.2.4.9 Recommendations

This is the first version of UAV Real-time Data Acquisition with Wireless Telemetry with some limitation and technical errors. Yet, the operation of the system can be improved with the following recommendation for future versions of the project:

- PCB printed circuit boards with copper traces are used rather than wires connection.
- Rechargeable battery (7-12V) can be used rather than non-rechargeable battery (9V battery).
- Voltage regulator can be used to ensure constant DC supply voltage to power the Arduino Nano, preventing abnormal operation of the circuits.
- Better transceivers with higher output voltage and higher RF frequency bands (915MHz) can replace nRF905 transceivers such as CC1101, HC12 or APC220 transceiver modules.
- The codes for programming the microcontroller can be improved by using ‘switch – case’ function and other functions.

4.3 Development and Conclusions

The UAV Real-time Data Acquisition with Wireless Telemetry has ensured basic requirements and operations when tested. Yet, the appearance of limitations and technical errors is inevitable. Future improvements based on limitations and recommendations can help enhance the overall system and guarantee a better user experience.

4.4 Delivery

The completed product will be delivered to the project sponsor – John Little at Flight One Academy on Thursday 4th February 2021.

The demonstration of the operation of the UAV Real-time Data Acquisition with Wireless Telemetry system will take place on the same day at different location due to restriction on flying drones near airport.

Glossary of Terms

UAV	Unmanned Ariel Vehicle
IMU	Inertial Measurement Unit
UHF	Ultra-High Frequency
I2C	Inter-Integrated Circuit
SPI	Serial Peripheral Interface
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
RGB	Red Green Blue
DPDT	Double Pole Double Throw

Reference

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