Single-Stage Rocket Avionics

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Abstract

We work on the electronics needed in a single-stage rocket. We present research on the various components and technologies used to support full flight; from the timer, to the trigger launch, data collection and in-flight data processing, to parachute deployment.

Contents

1 On Board Flight Electronics

On-board electronics primary roles:

- Altitude tracking
- Location tracking
- Data logging
- Parachute deployment

Prior to the apogee the electronics is concerned with the rocket's current flight phases. Post apogee, the electronics is concerned with the rocket's parachute deployment and recovery.

2 Hardware Implementation

In this section, we give a review and outline of the various hardware components to be implemented into the rocket avionics as well as details into their uses and functions.

2.1 Electronics Components

2.1.1 Microcontroller

For the microcontroller, we use the ESP8266/ESP32 for the following reasons:

- High processing power and ROM to size ratio.
- Compatible with both Arduino and Micropython.
- Cheap and affordable.
- Has an inbuilt BMS (Battery Management System).

The microcontroller forms the brain of the avionics. It analyses, records and does calculations on all readings received from the sensors.
Timing is also maintained and controlled by the microcontroller. The timing is integral in the launch sequence, launch trigger and the deployment and rescue stage.

2.1.2 Sensors

- BMP180 Barometric Pressure/Temperature/Altitude sensor priced at $Ksh150$.
- NEO-6M GPS module with EEPROM priced at $Ksh800$.
- MPU9250 9-DOF 3-Axis Accelerometer, Gyro, & Magnetometer priced at $Ksh800$.

2.1.3 Data Transmission

In-flight data transmission will be handled using RF transmitter and receiver modules; the RF transmitter on board the rocket while the receiver is on the ground station.
Data being streamed from the rocket to the ground stations includes:

- Altitude readings from the altimeter.
- Pressure readings from the pressure sensors.
- GPS positions from the GPS modules.
- Gyroscopic orientation from the gyro.
- Velocity and acceleration from the accelerometer.
- Temperature readings from the temperature sensor.

2.1.4 Motors and Actuators

The actuators handle the parachute deployment and recovery systems. The preferred actuator being the servo motor - *SuperLight Micro Servo*.
Using the sensors on board the vessel, the microcontroller will monitor the altitude and acceleration of the vessel. The actuators triggered to activate the deployment and recovery systems when the microcontroller observes a falling altitude and an acceleration vector directed downwards towards the earth's surface.

2.1.5 Energy Sources

The electrical energy sources are required to power the microcontroller and the ensemble of sensors and peripherals used in the rocket.
The microcontroller can function under either $3.7V$ or $5.0V$ battery supply. We however prefer the $9.0V$ battery supply which can be sourced from a $9.0V$ Alkaline battery.
Projected extra energy demands due to the many sensors can be supplemented using another $9.0V$ Alkaline battery.

2.2 Design, Fabrication and Prototyping

This sub-section looks at the circuit design and fabrication. We go into details on the materials needed and used to build a working prototype.

2.2.1 Circuit Boards

We make use of breadboards and copper clad boards.
Breadboard to be used for testing various designs before committing them to the final circuit design.
Copper clad boards to be used for prototype tests and eventually make it to building out the final circuitry to be installed onto the rocket.

2.2.2 Soldering

We make use of soldering iron and soldering wire to solder in components for a final testable prototype.

2.2.3 Circuit Schematics

In this sub-section, we look at all the circuit schematics to be implemented.
Inertial Measurement Unit (IMU)

MPU9250 9-DOF 3-Axis Accelerometer, Gyro, & Magnetometer
This MPU9250, which is a multi-chip module (MCM) consisting of two dies integrated into a single QFN package. One die houses the 3-Axis gyroscope and the 3-Axis accelerometer. The other die houses the AK8963 3-Axis magnetometer from Asahi Kasei Microdevices Corporation. Hence, the MPU-9250 is a 9-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, and a Digital Motion Processor (DMP). The MPU-9250 also features an embedded temperature sensor. This module includes pull-up resistors on the SDA, SCL, and nCS lines, pull-down resistors on the FSYNC and AD0 lines, and an on-board 3.3V voltage regulator allowing you to power the module from 5V sources such as an Arduino. If you desire to power the module from 3.3V you can bridge the solder jumper next

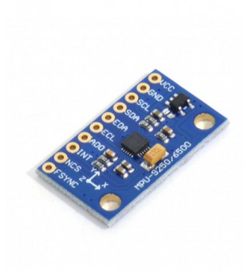

Figure 1: MPU9250 9-DOF module.

to the voltage regulator to bypass the regulator.
Specifications

- Ten pin male header.
- On-board pull-up resistors on SDA, SCL, and nCS.
- On-board pull-down resistors on FSYNC and AD0.
- 3-Axis Accelerometer with a range up to $\pm$ 16 g and sensitivity up to 16,384 LSB/g.
- 3-Axis Gyroscope with a range up to $\pm$ 2000 deg/sec (dps) and sensitivity up to 131 LSB/deg/sec.
- 3-Axis Magnetometer with a range $\pm$ 4800 μT and sensitivity 0.6 μT/LSB.
- Supply Voltage: $4.4V$ to $6.5V$ or $3.3V$ if you solder the solder jumper near the on-board voltage regulator.
- Interface: I2C.
- I2C Address 0x68 by default, 0x69 if AD0 is pulled high.
- Board Dimensions: 25.5mm long $\times$ 15.4mm wide, 3mm inside diameter of mounting holes.
- Weight: 2.72g.

It uses accelerometers in all three principle directions (x, y, and z axes) to measure the acceleration of the rocket during flight. The next 3 degrees of freedom are the angular rates that the rocket experienced during flight measured by gyroscopes. Finally, a magnetometer measured the magnetic field strength along the three axes.

BMP180 Barometric Pressure/Temperature/Altitude Sensor
Measuring the absolute pressure of the environment using a digital barometer such as this has some interesting applications. By converting the pressure measured into altitude, you have a reliable sensor for determining the height of your robot, plane or projectile!

Using a sensor as capable as the BMP180 you can achieve accuracy of 1m, with noise of only 17cm in ultra high resolution noise. The device will operate at only 0.3uA meaning low current draw for battery powered applications.
The BMP180 comes fully calibrated and ready to use. As the device operates over I2C we've added optional I2C pull ups that can be enabled using the PU (pull up) jumper on the board for your convenience and ease during breadboarding.
Using I2C, the device provides pressure and temperature as 16bit values, which are used along with calibration data within the device are used to provide a temperature compensated altitude

Figure 2: BMP180 Barometric Pressure/Temperature/Altitude Sensor module.

calculation.
Specifications

- 1.8V to 3.6V Supply Voltage
- Low power consumption - 0.5uA at 1Hz
- I2C interface
- Max I2C Speed: 3.5Mhz
- Very low noise - up to 0.02hPa (17cm)
- Fully calibrated
- Pressure Range: 300hPa to 1100hPa (+9000m to -500m)
- Weight: 1.18g
- Size: 21mm x 18mm

3 Design and Functionality Summary

Function	**Component**	**Weight**
Deploy, skid and decouple Drogue and Main parachutes	Servo motor (spring ejection mechanism or black powder techniques suggested)	$\approx 100g$
Evaluate temperature, Pressure, and Altitude	BMP180 sensor module	$\approx 400g$
On-board flight computer control and management	ESP8266/ESP32 microcontroller	$\approx 250g$
Inertial Measurement Unit (IMU) for recording the rocket's body-fixed acceleration and angular velocity during flight	MPU9250 9-DOF 3-Axis Accelerometer, Gyro & Magnetometer	$\approx 300g$
RF Transmission	LoRa (Long Range Radio)	
Powering the avionics and electronics systems	preferably a three-cell 11.1-volt, 1000 mAh Lithium Polymer (LiPo) Battery	$\approx 100g$
		Total $= \approx 1200g$

4 Programming and Testing.

E-Bay (Flight Control) Mission Tasks

- detect launch accurately
- detect apogee accurately
- send the parachute ejection signal accurately

Criteria for detecting launch:

- the linear acceleration in the vertical direction is more than $5m/s^2$
- the gained altitude has exceeded $5m$.

The above criteria signal a successful launch

Criteria for detecting apogee:

- launch has been detected and was successful
- identify and recognize an apogee when the current altitude reading is less than the highest (max) recorded altitude reading by $1m$.

Criteria for parachute deployment:

- Apogee has been detected
- *Time constraints have been triggered yet apogee has not yet been detected

*The time constraint mechanism acts as a fail-safe mechanism for parachute deployment. The are set minimum and maximum time periods after launch that can allow for parachute deployment.
If for some absurd reason the e-bay detected apogee right after launch, the minimum time constraint prevents parachute deployment. Likewise, if apogee fails to be detected after launch and rocket has already began it's descent, the parachute will only be deployed after the maximum time constraint.
The time constraints are determined using physics launch simulation code.

References

[1] Makenzi W. Stephen, Makori O. Charles and Mwangudza Mwasaha, "A single stage prototype rocket for atmospheric profiling", Dept. Aerospace and Aviation Engineering, T.U.K Italian Space Agency – San Marco Project, (2018).

References