CAN-RGX: Embedded Subsystem

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Introduction

This document describes the embedded subsystem onboard team “FAM”’s (fluids affect by magnetism) experiment for the Canadian Reduced Gravity Experiment Design Challenge.

Contents

1. Overview

The embedded subsystem is responsible for acquiring data from sensors, using this data to initiate control sequences, and streaming data to the onboard PC. The sensors are as follows:

1. MPU9250: 3-axis accelerometer, gyroscope, and magnetometer, 1 in quantity
2. 18B20: 1-wire digital temperature sensor, 10 in quantity

The systems to which control signals will be asserted are as follows:

1. DRV8871: H-bridge, 6 in quantity
2. TEC: thermoelectric cooler, 2 in quantity

The proceeding sections will describe each of these in more detail, and subsequently, their integration will be described.

2. MPU9250 (accelerometer, gyroscope, magnetometer)

As the MPU9250 measures acceleration, it is capable of automatically triggering the experiment through software once the acceleration magnitude is below a certain threshold. It can also detect other events of interest throughout the flight. All these events can be detected according to the following algorithm, where:

1. w_y is the rate of change of the pitch of the aircraft about the y-axis (also called *angular rate*). Note that pitch is the angle between the nose of the aircraft and the horizon

2. a_z is the vertical acceleration of the aircraft. **Note that $a_z > 0$ implies the aircraft is accelerating downward**.

Algorithm 1 Algorithm for triggering flight events

```
procedure FLIGHTEVENTS
    Measure w_y and a_y
    if w_y > 2.5 AND a_z < −14.715 (1.5G) then
        return Transition from Straight and level to Pull Up
    else if w_y < 0 AND a_z > −0.981 (0.1G) then
        return Transition from Pull-up to Reduced Gravity
    else if w_y > 0 AND a_z < −0.981 (0.1G) then
        return Transition from Reduced Gravity to Pull-Out
    else
        return No flight event
```

Note: It was suggested that a manual mechanism be provided to trigger the experiment in addition to the automated software protocol

The MPU9250 is also used to measure the magnetic field generated by the electromagnet. This allows the magnetic field to be generated to its maximum possible value while maintaining safety limits.

At a minimum, the MPU9250 must be used to measure the following:

- a_z (16 bits, full-scale range $\pm 2g$)
- w_y (16 bits, full-scale range ± 250 [deg $/s$])
- H_x, H_y, H_z (14 bits each, full-scale range ± 4800 [uT])

Note that these full-scale ranges were the defaults and also the most suitable since they provided the highest resolution for the window of interest.

Due to the importance of the readings from the MPU9250, it was decided that the motion processing algorithms should be run at a high rate, about 500 [Hz]. Also, note that the MPU9250 features offset registers that can be user-programmed to eliminate dc offsets. It also features an integrated digital low-pass filter whose bandwidth can be set using the `DLPF_CFG` and `A_DLFPCFG` for the gyroscope and accelerometer, respectively. Note that lower bandwidth comes at the cost of increased delay, on the order of milliseconds.

9.1 Orientation of Axes

The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier (•) in the figure.

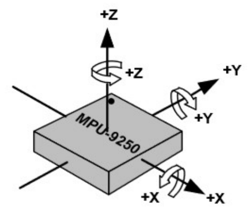

Figure 4. Orientation of Axes of Sensitivity and Polarity of Rotation for Accelerometer and Gyroscope

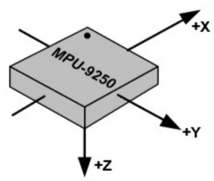

Figure 5. Orientation of Axes of Sensitivity for Compass

Figure 1: Orientation of axes for MPU9250 data (page 38 of datasheet).

5.6 HXL to HZH: Measurement Data

Addr	Register name	D7	D6	D5	D4	D3	D2	D1	D0
Read-only register									
03H	HXL	HX7	HX6	HX5	HX4	HX3	HX2	HX1	HX0
04H	HXH	HX15	HX14	HX13	HX12	HX11	HX10	HX9	HX8
05H	HYL	HY7	HY6	HY5	HY4	HY3	HY2	HY1	HY0
06H	HYH	HY15	HY14	HY13	HY12	HY11	HY10	HY9	HY8
07H	HZL	HZ7	HZ6	HZ5	HZ4	HZ3	HZ2	HZ1	HZ0
08H	HZH	HZ15	HZ14	HZ13	HZ12	HZ11	HZ10	HZ9	HZ8
Reset		0	0	0	0	0	0	0	0

Measurement data of magnetic sensor X-axis/Y-axis/Z-axis

HXL[7:0]: X-axis measurement data lower 8bit
HXH[15:8]: X-axis measurement data higher 8bit
HYL[7:0]: Y-axis measurement data lower 8bit
HYH[15:8]: Y-axis measurement data higher 8bit
HZL[7:0]: Z-axis measurement data lower 8bit
HZH[15:8]: Z-axis measurement data higher 8bit

Measurement data is stored in two's complement and Little Endian format. Measurement range of each axis is from -32760 ~ 32760 decimal in 16-bit output.

Measurement data (each axis) [15:0]			Magnetic flux density [μT]
Two's complement	Hex	Decimal	
0111 1111 1111 1000	7FF8	32760	4912(max.)
|	|	|	|
0000 0000 0000 0001	0001	1	0.15
0000 0000 0000 0000	0000	0	0
1111 1111 1111 1111	FFFF	-1	-0.15
|	|	|	|
1000 0000 0000 1000	8008	-32760	-4912(min.)

Table 4 Measurement data format

Figure 2: Magnetometer register map and corresponding scales from page 50 of the register map.

3. 18B20 (temperature sensor)

The temperature sensor is used to monitor the temperature of the electromagnet. It provides digital signal to the microcontroller for reading, strictly following a 1-wire protocol. Byte-long codes are listed in pages 10 through 12 of the datasheet, which are transmitted LSb first. Each sensor has a unique ROM address which can be identified using the Search ROM cycle documented on page 10 of the datasheet.

4. DRV8871 (H-bridge)

The H-bridges are used to generate magnetic fields of various strengths in the coils surrounding the fluid cell, and to generate various heat gradients using the TECs. PWM is used in both cases.

5. TEC (thermoelectric cooler)

The TEC plates are used to supply heat and cooling to the fluid.
Power data should be acquired at about 500 Hz

6. Integration

The aforementioned components were integrated using a STM32F411RE microcontroller on a Nucleo-F411 development board.

6.1 Data Logging

Data from all sensors were logged and sent to the onboard PC over a 256 [kHz] UART channel. The packet format was as follows:

Parameter	Data Type	Size (bytes)	Offset (bytes)	Units	Range	Positive Sign Convention
Magnet power	TODO	TODO	TODO	TODO	TODO	TODO
TEC power	TODO	TODO	TODO	TODO	TODO	TODO
Temperature	TODO	TODO	TODO	TODO	TODO	TODO
Acceleration	TODO	TODO	TODO	TODO	TODO	TODO

Table 1: Form of packet to PC

Additionally, the aircraft provided its own data as a UDP packet on port 5124, which could be read by the onboard PC so long as it had an IP address of 132.246.192.[25..50]. A breakdown of the packet can be found in “NRC Nav Packet.xlsx”.