

Lab 3: MEMS Accelerometer, Timer and Interrupts

ECSE 426 – Microprocessor Systems



McGill University

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# 1. Abstract

# 2. Problem Statement

The goal of this experiment is to create a system that detects the orientation of the STM32F4 discovery board. The rotation of the board around its axes is detected using the built-in accelerometer. However, the accelerometer cannot determine the yaw (rotation around the board’s z-axis) since it does not result in a change in acceleration. Only the roll (rotation around the board’s x-axis) and pitch (rotation around the board’s y-axis) can be found using the accelerometer. When the accelerometer’s raw data becomes available, the processor will calibrate it using a pre-built calibration matrix and filter it using a Kalman filter whose parameters are experimentally defined. In order to make sense of the data, it needs to be converted into an angle in degrees. This conversion is done using the arctan function available in the math library. Once the angle is available, it can be compared against the user input. The user is prompt to enter a target angle for both the roll and the pitch using a 4x4 external keypad. As the user tilts the board, an indication on the 7-segment displays an animation to help the user directing the board toward the target angle. Once the user is within five degree of the target roll angle, the 7-segment display will show the current angle captured by the accelerometer. This measured angle is expected to be within four degrees of accuracy compared to the actual angle

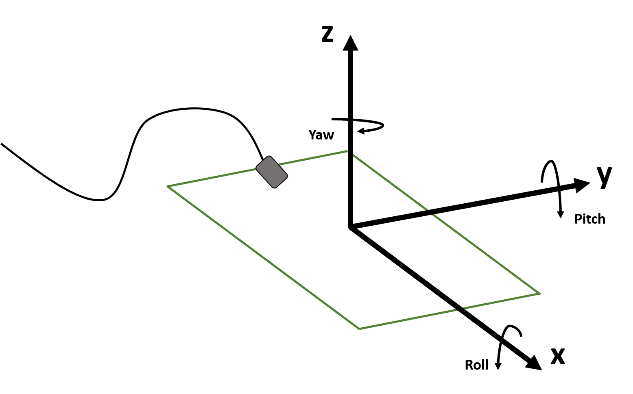
# 3. Theory and Hypothesis

## 3.1. Accelerometer

### 3.1.1. Orientation

--- Relationship between 3 axis and 3 angles (one of them cannot be detected)

--- Figure showing the axis and angles



### 3.1.2. Acceleration

--- How the angle is quantified

## 3.2. Data Calibration and Filtering

--- When data ready (signaled by an interrupt flag), perform calibration

### 3.2.1. Data Calibration

--- 6 positions expected (not normalized?) acceleration (0 0 1, 0 0 -1, 0 1 0, 0 -1 0, 1 0 0, -1 0 0)

--- Calibration operation (need equation)

### 3.2.2. Data Filtering

--- Kalman filter (what’s the purpose of filtering?)

### 3.2.3. Data Interpretation

--- Normalize acceleration

--- Convert from acceleration to angle in radian (need equation)

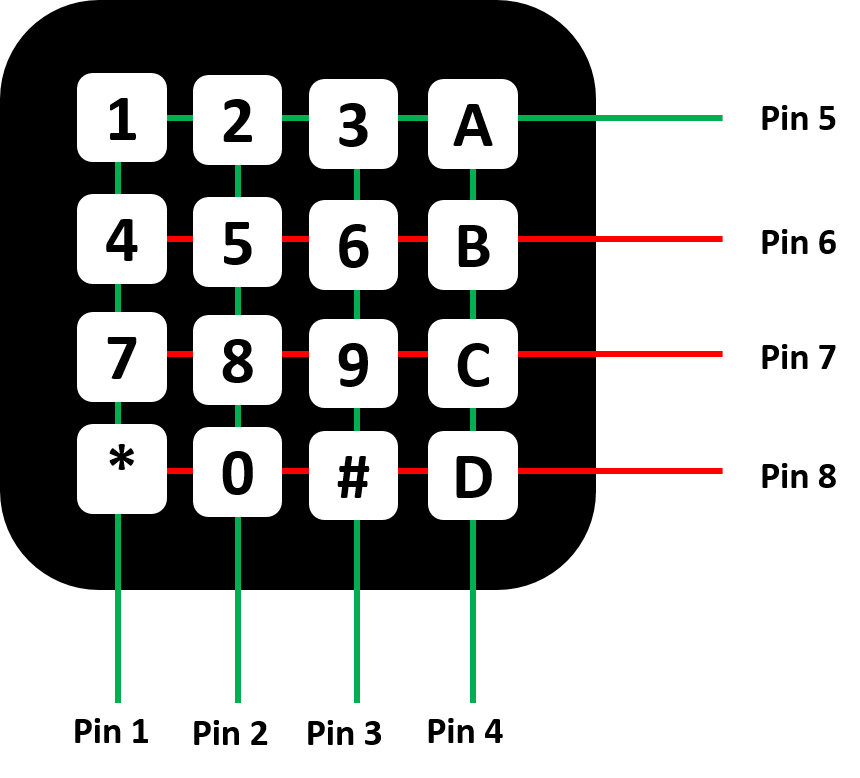
--- Alternative way of getting the angle (lookup table)

## 3.3. External Keypad

### 3.3.1. Circuit Layout

--- Determine connections (experimental)

--- Figure showing the layout



### 3.3.2. Data Acquisition

--- Set, detect, reverse, detect

### 3.3.3. Handling Key Bouncing

--- Sample the same digit multiple times

--- Compare with previous value to detect changes

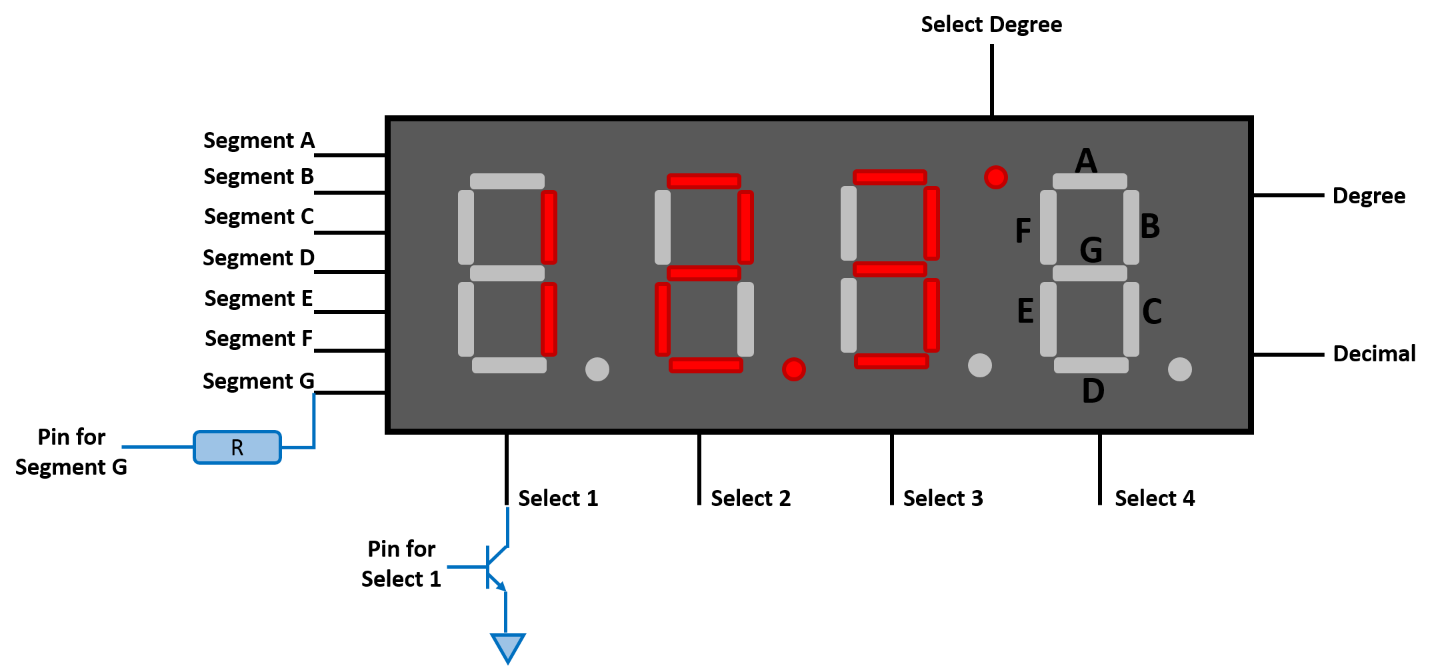
--- Ignore short period NO INPUT signal

## 3.4. External 7-Segment Display

### 3.4.1. Circuit Layout

--- Resistors and transistors to protect the circuit against possible high current flow

--- Figure showing the layout



--- Use of resistors and transistors

### 3.4.2. Data Display

--- Select digit, display, next digit

## 3.5. Timing

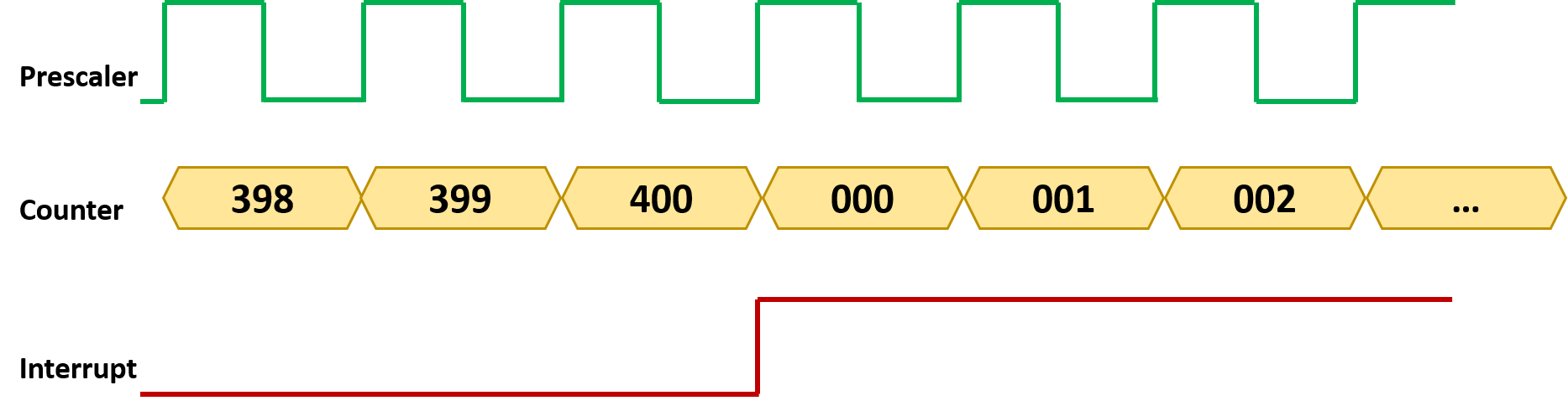
### 3.5.1. Timing Based on Sample Rate

--- Interrupt when sample is ready

### 3.5.2. Timing Based on Hardware Timer

--- Clock frequency, Prescaler and Period 🡪 Interrupt (show equation)

--- Figure to show the relationship



# 4. Implementation

## 4.1. Component Configuration and Initialization

### 4.1.1. GPIO Configuration

--- Includes PE0 for accelerometer

--- 7-segment pins

--- On board LEDs

### 4.1.2. Accelerometer Configuration, Accelerometer Interrupt and Interrupt Handler

--- Pin and channel

--- Frequency of the interrupt

### 4.1.3. Timer Configuration, Timer Interrupt and Interrupt Handler

--- Frequency of the interrupt

--- Interrupt variables (TIM3\_Interrupt and TIM3\_Interrupt\_Count)

## 4.2. Collect User Input

### 4.2.1. Initialize Keypad

### 4.2.2. Return User Input

### 4.2.3. Improvement on Keypad

## 4.3. Data Sampling

--- Continuous sampling

--- Signal processor when data is ready

## 4.4. Data Processing

--- Show calibration data in **Appendix A**

--- Kalman parameters, show Matlab simulation results in **Appendix B**

## 4.5. Data Comparison

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## 4.6. Result Display

### 4.6.1. Visual Feedback

--- Animation to direct user to move in the right direction

### 4.6.2. Display Current Angle

--- Only displaying the beta angle

## 4.7 Continuous Process

--- Continuous process until user presses reset

# 5. Testing and Observation

## 5.1. Accelerometer Calibration

--- Within 4 degree accuracy

--- Low accuracy, therefore could use lookup table instead

--- Using complex math functions on floating points --- more power hungry

--- Using lookup table --- less accurate --- more memory needed --- less power

## 5.2. Kalman Filter

--- Choice of constants

# 6. Conclusion

# Reference

# Appendix A – Calibration Data