CUED - Engineering Tripos Part IIB 2022-2023 **Module Coursework**

Module	4B25	Title of report	Coursework 4

Date submitted: 16/03/23	Assessment for this module is ☐ 100% / ☐ 25% coursework of which this assignment forms _____ %

UNDERGRADUATE and POST GRADUATE STUDENTS

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Feedback to the student

☐ **See also comments in the text**

		Very good	**Good**	Needs improvmt
CONTENT	**Completeness, quantity of content:** Has the report covered all aspects of the lab? Has the analysis been carried out thoroughly?			
	Correctness, quality of content Is the data correct? Is the analysis of the data correct? Are the conclusions correct?			
	Depth of understanding, quality of discussion Does the report show a good technical understanding? Have all the relevant conclusions been drawn?			
	Comments:			
PRESENTATION	**Attention to detail, typesetting and typographical errors** Is the report free of typographical errors? Are the figures/tables/references presented professionally?			
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4B25: Coursework 4

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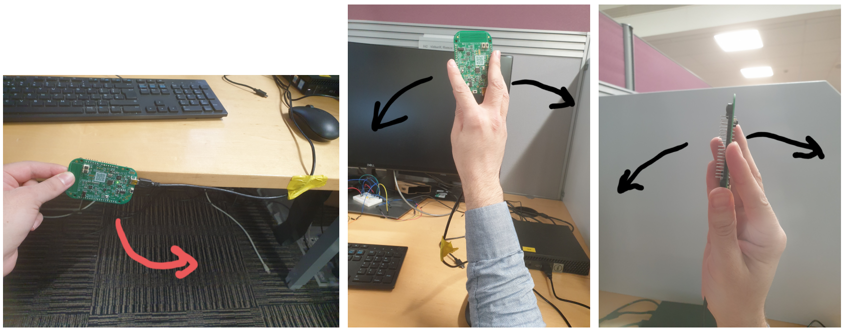
1 Implementation

The implemented classifier for this project classifies the following activities: a pendulum-like swing of the KL03 board from the USB programming cable taped to a table, five hand-waves in the XY plane, and four hand-waves in the YZ plane. Figure 1 shows illustrative outlines of what these activities look like in practise. The implementation relies on using the MMA8451Q 3-axis accelerometer to sample the acceleration waveforms in the X, Y, and Z axes, and comparing the sampled waveforms against respective X, Y, and Z template waveforms that correspond to the different activities. The template waveforms are pre-computed externally and then stored back into the microcontroller. The uncertainty in the activities is taken into account by considering the classification waveform templates as error ranges that are externally pre-computed from the means and standard deviations of a number of captured waveforms. We also report uncertainty as a percentage of valid samples of the test waveform that adhere to the activity template waveform.



(a) (b) (c)

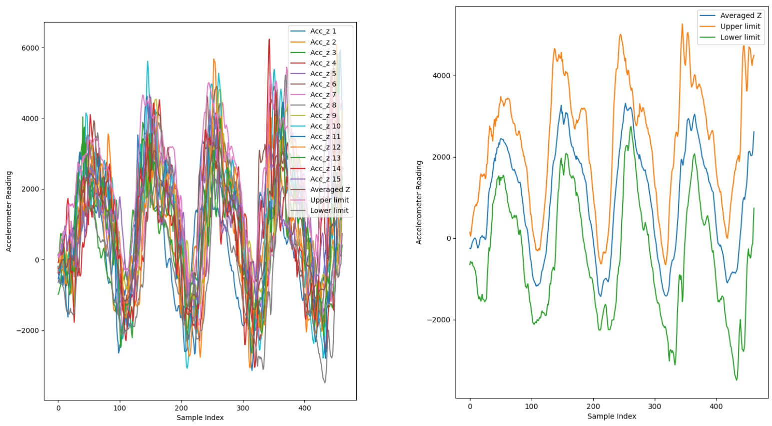
Figure 1: The different activities that can be classified. 1a: Pendulum-like swinging motion from the USB cable. 1b: Side-to-side waving motion. 1c: Forwards and backwards waving motion.

2 Template Waveform Computation

To be able to classify activities, template waveforms for those activities are required so that a captured time-series of accelerometer readings can be compared against to compute the classification result. To do this, we first capture a number of waveforms for the 3 axes from the accelerometer, from which the template waveform will be computed. In our case, we use 15 waveforms with 461 samples in each waveform. Figure 2a shows the Z components of these waveforms for the activity in figure 1b. From these captured waveforms, we compute the means and standard deviations at every sample point across the 15 waveforms. So the result is two arrays which correspond to the means and standard deviations for each index point out of the 461 samples. We can get the template waveform upper bound by adding two times the point-wise sample standard deviations to the point-wise sample means. Similarly, we can subtract two times the point-wise sample standard deviations to the point-wise sample means to get the lower bound. This is shown in the equations in 1, for $i = 1, 2, 3, ...461$ waveform samples. U_i and L_i are the upper and lower bounds at each sample index, μ_i is the sample index mean, and σ_i is the sample index standard deviation.

$$U_i = \mu_i + 2 * \sigma_i \qquad\qquad L_i = \mu_i - 2 * \sigma_i \tag{1}$$

Once the upper and lower bound integer arrays are computed for each of the three axes, they are stored back into the microcontroller for classification. The resulting bounds from this calculation are shown in figure 2b.



(a) (b)

Figure 2: 2a: Z components of the 15 captured waveforms for the activity in 1b. 2b: the upper and lower limits that are computed from the means and standard deviations of the waves in 2a. These limits comprise the activity template waveforms that are stored back into the microcontroller for classification.

3 Template Waveform Array Storage

One issue that caused some trouble in this implementation was memory constraints. Each activity requires storage of the upper and lower limits of a template waveform for 3 different axes, where each limit array is composed of 461 16-bit signed integers. Therefore, in total we require 5532 bytes (5.5 KB) of storage for each activity and since we have 3 activities we would need 16,596 bytes (16.6 KB). This would not fit within the KL03 which only has 2 KB of SRAM storage. Therefore, I found a workaround solution that was based off of using the 32 KB program flash memory instead. First the arrays would be split in half and stored inside functions, so that they can be stored within stack frames only when they are needed. Therefore, only one half of the array would need to exist within memory at any given instance and then would be removed from the stack once it is no longer required. With three activities the `.text` section also began to overflow. Therefore, all the other functionalities that come with the Warp firmware by default had to be removed.

4 Algorithm

The main operation of the algorithm happens as the test waveform samples are being captured. This avoids the need to store the test waveform, thereby reducing memory requirements, which are already constricted. As a sensor reading is taken, the axis values are checked against their corresponding indices in the activity template waveform, to see whether they lie within the acceptable range. For that to be the case, the value must be greater than the lower bound and less than the upper bound. The number of invalid readings n_{inv} is kept track of, and is used to calculate the confidence level percentage C using equation 2. N is the total number of readings in a given axis, so we multiply it by 3 to find the total number of readings across all axes.

$$C = \frac{3N - n_{inv}}{3N} * 100 \tag{2}$$

If C is above a threshold percentage value (in this implementation it is taken to be 70), a positive classification result is reported for the test waveform based on the activity that is being checked. Uncertainty quantification is inherently taken into consideration due to the usage of the template waveforms which are calculated based on the means and standard deviations of the sample distributions of the captured activity waveforms. A further report on uncertainty is also given through the confidence level percentage. Figure 3 shows an example classification report for a given activity test case.

```
Not a pendulum swing. Confidence: 14%
Not five side-to-side handwaves. Confidence: 36%
=>Four forwards and backwards handwaves. Confidence: 77%
```

Figure 3: Classification report with a positive result for four forwards and backwards hand-waves. Uncertainty is reported using the confidence level metric calculated using equation 2.