MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

DETECTION OF CARGO PACKAGE DROP

ALPER TUNGA ERDOĞAN

MASTER THESIS
Department of Electrical and Electronics Engineering

Thesis Supervisor
Doç.Dr. ENGİN MAŞAZADE

ISTANBUL, 2022

MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

DETECTION OF CARGO PACKAGE DROP

525018036

MASTER THESIS
Department of Electrical and Electronics Engineering

Thesis Supervisor
Doç.Dr. ENGİN MAŞAZADE

ISTANBUL, 2022

MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES

ALPER TUNGA ERDOĞAN, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled "**Detection of cargo package drop**", on November 9, 2022 and has been found to be satisfactory by the jury members.

Jury Members

Doç. Dr. Engin Maşazade (Advisor)
Marmara University ..... (SIGN).....

Doç. Dr. Onur Cihan (Jury Member)
Marmara University..... (SIGN).....

Prof. Dr. Duygun Erol Barkana (Jury Member)
Yeditepe University ..... (SIGN).....

APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Alper Tunga ERDOĞAN be granted the degree of Master of Science in Department of Electrical and Electronics Engineering, Electrical and Electronics Program on

Director of the Institute

ACKNOWLEDGEMENT

Since the first day, I started my thesis studies, my thesis advisor Doç. Dr. Engin Maşazade supported me far beyond my expectations. I would like to thank him for his time and valuable guidance during this long process.

I would like to thank my wife Sibel and my son Kerem Alp for their unwavering support throughout my studies.

November 2022 **Alper Tunga ERDOĞAN**

CONTENTS

Chapter 1 - INTRODUCTION 1

1.1 Concept of the Thesis 1

1.2 Literature Review 1

1.3 Contributions of the Thesis 2

1.4 Organization of the Thesis 3

Chapter 2 - SYSTEM MODEL 4

2.1 Concept Design 4

2.2 Hardware Design 6

2.2.1 Renesas R5F100SLA microcontroller 8

2.2.2 Bosch BMI160 module 8

Chapter 3 - IMPLEMENTATION 10

3.1 Embedded Software Development using e2 studio 10

3.2 Data Collection using Python 12

3.3 Machine Learning Implementation using MATLAB 16

3.4 Low Power Fall Detection Device 21

Chapter 4 - NUMERICAL RESULTS 23

4.1 The Dataset obtained by data collection 23

4.2 Detailed analysis of any two samples from the dataset 28

4.3 Train and Test Accuracy 29

4.4 Current Consumptions in Sleep mode and Run mode 30

Chapter 5 - CONCLUSIONS FUTURE RESEARCH DIRECTIONS 32

ABSTRACT

DETECTION OF CARGO PACKAGE DROP

The spread of e-commerce in recent years has led to a rapid increase in the volume of transactions in this area. Currently, with the effect of the pandemic, it is now accepted by most that high-priced or fragile items can also be obtained through e-commerce. However, a major issue is how to make sure existing logistics companies move such sensitive goods safely. To solve this problem, a very low-power device design is proposed in this thesis. The device is fixed on the package or box to be sent directly by cargo and detects whether the cargo has fallen within the time elapsed until it is delivered to the customer. Accelerometer and gyroscope were used for fall detection. In addition, embedded software has been applied on the microcontroller side to operate at low power so that the device can be used again in a short time without the need for battery replacement.

ÖZET

KARGO PAKETİ DÜŞMESİNİ ALGILAMA

Son yıllarda e-ticaretin yaygınlaşması bu alandaki işlem hacminin hızla artmasına neden olmuştur. Şu anda pandeminin de etkisiyle, yüksek fiyatlı veya kırılgan eşyaların da e-ticaret vasıtasıyla temin edilebileceği, artık çoğu kişi tarafından kabul edildi. Ancak önemli bir sorun, mevcut lojistik şirketlerinin bu tür hassas malları güvenle taşındığından nasıl emin olunacağıdır. Bu sorunu çözmek için bu tezde çok düşük güçle çalışan bir cihaz tasarımı önerilmektedir. Tasarlanan cihaz doğrudan kargoyla gönderilecek olan paketin üzerine sabitlenecek ve müşteriye teslim edilene kadar geçen sürede, kargonun düşüp düşmediği tespit edecektir. Düşme tespiti için ivmeölçer ve jiroskoptan faydalanılmıştır. Ayrıca kısa sürede pil değişimi gerektirmeden cihazın tekrar kullanılabilmesi için mikrodenetleyici tarafında düşük güçte çalışmaya yönelik gömülü yazılım gerçekleştirilmiştir.

ABBREVIATIONS

APSIPA: Asia-Pacific Signal and Information Processing Association

CCRL: C Compiler for RL78 Family

EECSI: Electrical Engineering, Computer Science, and Informatics

GND: Ground

I²C or I2C: Inter-Integrated Communication

ICPCSI: IEEE International Conference on Power, Control, Signals, and Instrumentation Engineering

IDE: Integrated Development Environment

IEEE: Institute of Electrical and Electronics Engineers

IMU: Inertial Measurement Unit

RAM: Random Access Memory

SPI: Serial Peripheral Interface

SVM: Signal Vector Magnitude

TTL: Transistor – Transistor Logic

TxD: Transmit Data

USB: Universal Serial Bus

LIST OF FIGURES

Figure 1 The schematic of fall detection system 4

Figure 2 Accelerometer and gyroscope data directions 5

Figure 3 Renesas RL78/G13 series target board 6

Figure 4 Experimental setup on Renesas RL78/G13 series target board 7

Figure 5 Slide switch for power supply selection 7

Figure 6 BMI160 accelerometer and gyroscope module 9

Figure 7 Code Generator settings 11

Figure 8 e2-Lite Debugger 11

Figure 9 TTL to USB Converter 12

Figure 10 Data transfer from board to computer 13

Figure 11 Data transfer monitoring screen 14

Figure 12 Accelerometer graphic 15

Figure 13 Gyroscope graphic 16

Figure 14 Scatter plot of samples 17

Figure 15 Normalized scatter plot of samples 19

Figure 16 Decision boundary 21

Figure 17 Sample registered as not dropped 28

Figure 18 Sample registered as dropped 29

Figure 19 Train and test accuracy 29

Figure 20 Current consumption in Sleep mode 30

Figure 21 Current consumption in Run mode 31

LIST OF TABLES

Table 1 Power consumption comparison of microcontrollers 8

Table 2 Dataset obtained by data collection..... 23

Chapter 1 - INTRODUCTION

The way people shop is changing. Of course, the pioneer of this change is the internet, smartphones, artificial intelligence applications, etc. The last of these factors is undoubtedly the pandemic. At the beginning of the pandemic, we have seen intensely that in fact, a series of precautions must be taken in the transportation procedure for the cargo to arrive without any damage.

1.1 Concept of the Thesis

Shopping habits have changed rapidly in recent years. Consumers now prefer to order online rather than go to stores. This situation brings with it some problems. The first thing that comes to mind, of course, is that fragile items such as glasses and plates cannot be received from the cargo without any problems. In addition, some non-fragile products may also be damaged by falling. Let's consider an electronic product. There is a risk of damage to the product even after all tests have been completed, packaged, and boxed when leaving the factory. Because falling of the product due to excessive vibrations that may occur during transportation may cause damage to the electronic circuit inside the product. Even if the product does not seem to be damaged due to falling, problems with the solder in the electronic circuit may occur in the future. The proposed study in this thesis is a low-power device design. This battery-operated device is fixed on the cargo package and detects whether the product has fallen during transportation.

1.2 Literature Review

In the literature, there are various studies on fall detection. Falling is a common and significant cause of injury in elderly adults (> 65 years old), often leading to disability and death. (Huynh, Nguyen, Irazabal, Ghassemian, & Tran, 2015) For this reason, when the subject of fall detection is researched in the literature, it is seen that studies are mostly conducted on the perception of falls of elderly people. In these studies, an accelerometer was used as a fall detector. (Lan, Hsueh, & Hu, 2012) In some, an accelerometer and gyroscope are used together. (Guo, et al, 2015) In most articles, a threshold value is given to determine the level of perception, while in some articles, methods to distinguish daily

activities such as sitting, and walking are used. (Sorvala, Alasaarela, Sorvoja, & Myllylä, 2012) They also preferred to use Machine Learning algorithms such as Support Vector Machines and Back Propagation in cases where daily activities are distinguished. (Rescio, Leone, & Siciliano, 2013) (Jefiza, Pramunanto, Boedinoegroho, & Purnomo, 2017) The wearable device, which includes the accelerometer and gyroscope, also includes a communication module. In this way, the information that the person has fallen is transmitted to the necessary places. (Tan & Tinh, 2014) What's more, an interesting article showed that not only does it notify the fall, but also that injury can be prevented by deploying a wearable airbag in the event of a fall. (Sivaranjani, et al., 2017) In similar articles in the literature, it is seen that smartphones are used to detect falls instead of designing a device from scratch. (Rakhman, Nugroho, Widyawan, & Kurnianingsih, 2014)

Image processing techniques were used in some of the studies for fall detection. (Chen, Du, Luo, & Xiao, 2021) Of course, this requires a camera. However, it is not possible to use a camera in the project that is the subject of our thesis proposal. Because the device intended to be designed aims to transport fragile cargo packages more carefully and to detect whether they fall during distribution. In other words, the object to be determined whether it fell or not will not be in a position to be in a fixed camera frame at any time.

Finally, there is an article in the literature that is the closest to the result we want to reach as a result of this thesis study. But there was a different method tried. A piezoresistive pressure sensor is used in the study proposed in this article. With this flexible sensor, a flexible sensing circuit was designed and produced in the form of duct tape. According to the change in the impedance value measured by the sensor on this band, it is understood whether the package is deformed or not. (Chang, Chen, & Su, 2020)

1.3 Contributions of the Thesis

Contributions of the thesis can be listed as follows:

1. In the most similar study in the literature, piezoresistive pressure sensors included in the flexible sensing circuit of a custom-made tape exhibit impedance changes due to force-induced deformations. Although there is no deformation on the tape, the product

inside the box may be damaged. However, in our thesis, the drop of the box or the object is not detected according to the deformation on the tape, but with a device directly taped on the box.

2. All the studies in the literature are based on detecting the fall and then transmitting this situation to the relevant places via the communication module. In our thesis, it will be seen that not only does it detect the fall, but also this detection process can be done with very low power consumption. In this way, a device that can be used repeatedly without the need for frequent battery changes will be designed.

1.4 Organization of the Thesis

This thesis consists of five chapters; In Chapter 1, we present the introduction of the study, the literature survey, and the contributions of this thesis. In Chapter 2, we present the system model which gives a brief definition of concept design and hardware design. In Chapter 3, we present the embedded software implementation. In Chapter 4, we present our numerical results, and finally, we devote Chapter 5 to our conclusion and address future research directions.

Chapter 2 - SYSTEM MODEL

The system model was explained in two different groups concept design and hardware design. In the concept design part, there is an explanation for the theory of the study. In the hardware design section, it is explained how to move from theory to practice.

2.1 Concept Design

A low-power device was designed for the thesis. This device contains a battery, microcontroller, and sensor. As the sensor we use Bosch BMI160 which contains accelerometer and gyroscope together. Figure 1 illustrates the device designed in its simplest form. When BMI160 is used, we can benefit from interrupts at different stages. One of them is any-motion detection. This interrupt wakes the microcontroller from sleep mode. In this way, the microcontroller will not shorten the battery life during sleep. After the CPU wakes up, it receives accelerometer and gyroscope data from the sensor for 3 seconds, taking a sample every 10 milliseconds. The next stage is the calculation and decision-making phase. The signal vector magnitude (SVM) is calculated using,

$$SVM = \sqrt{x_i^2 + y_i^2 + z_i^2}$$

where the x, y, and z values are sampled by the accelerometer.

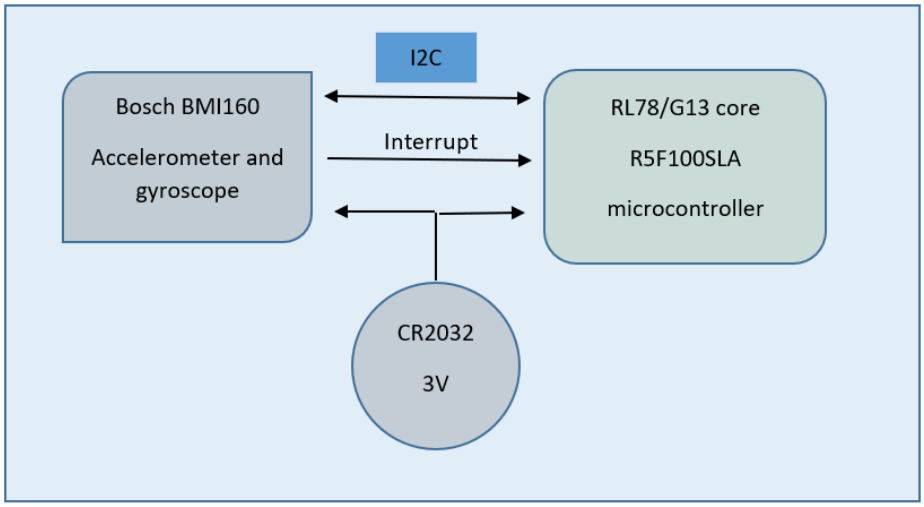


Figure 1 The schematic of fall detection system

Similarly, angular velocity can be found by using the angular velocities in the x, y, and z directions obtained from the gyroscope.

$$\omega = \sqrt{{\omega_x}^2 + {\omega_y}^2 + {\omega_z}^2}$$

where $\omega_x, \omega_y, \omega_z$ are angular velocities in x, y, and z directions.

will be found by using the angular velocities in the x, y, and z directions obtained from the gyroscope. Figure 2 shows the representation of these six variables on the coordinate plane.

Embedded software has been developed to analyze the change in signal vector magnitude and angular velocity values and decide whether the cargo package has dropped or not. A set of experimental data was used to extract the algorithm used in the embedded software.

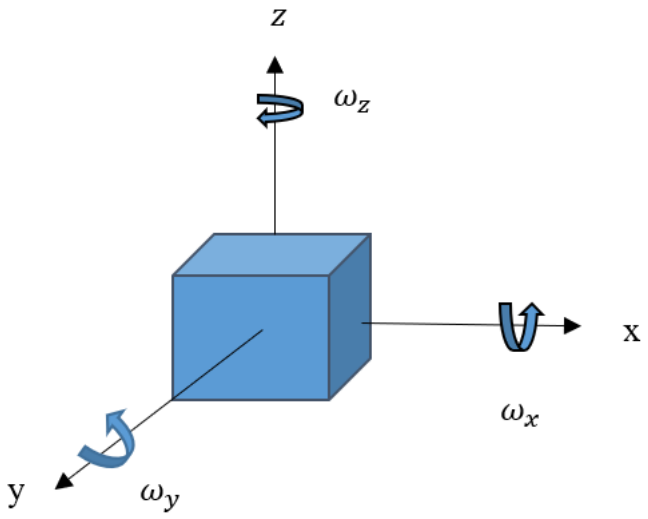


Figure 2 Accelerometer and gyroscope data directions

2.2 Hardware Design

Since the device designed to detect the drop of the cargo package must work with a battery, the selected microcontroller must also be able to operate at low power. This microcontroller is R5F100SLA from the RL78/G13 series of Renesas.

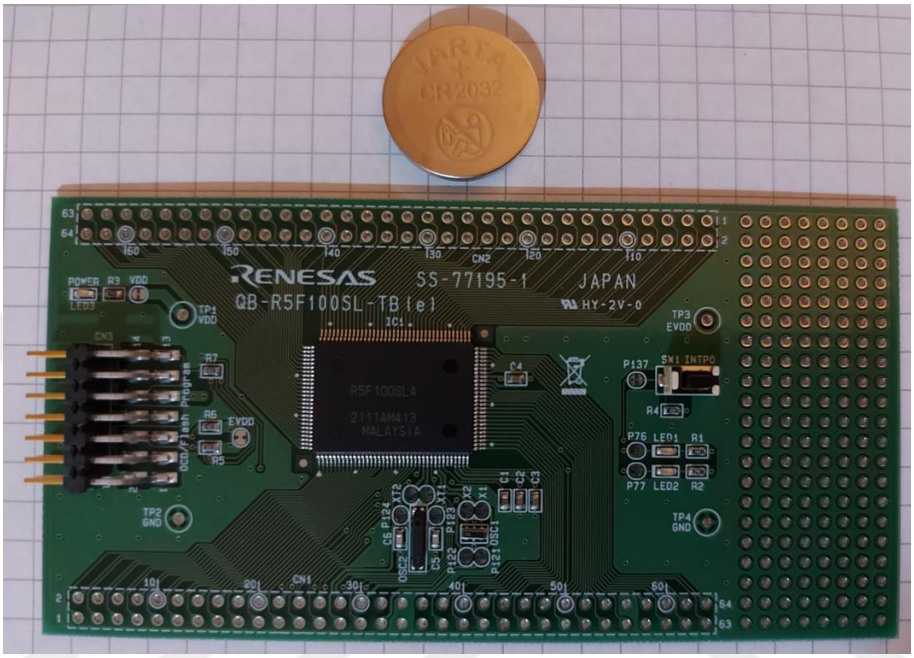


Figure *3* Renesas RL78/G13 series target board

The development board containing the R5F100SLA microcontroller produced by Renesas company is shown in Figure 3. As shown in Figure 4, the CR2032 battery, BMI160 sensor module, and slide switch are mounted to the empty part on the right side of the development board, and the connection cables between slide switch R5F100SLA and BMI160 are soldered.

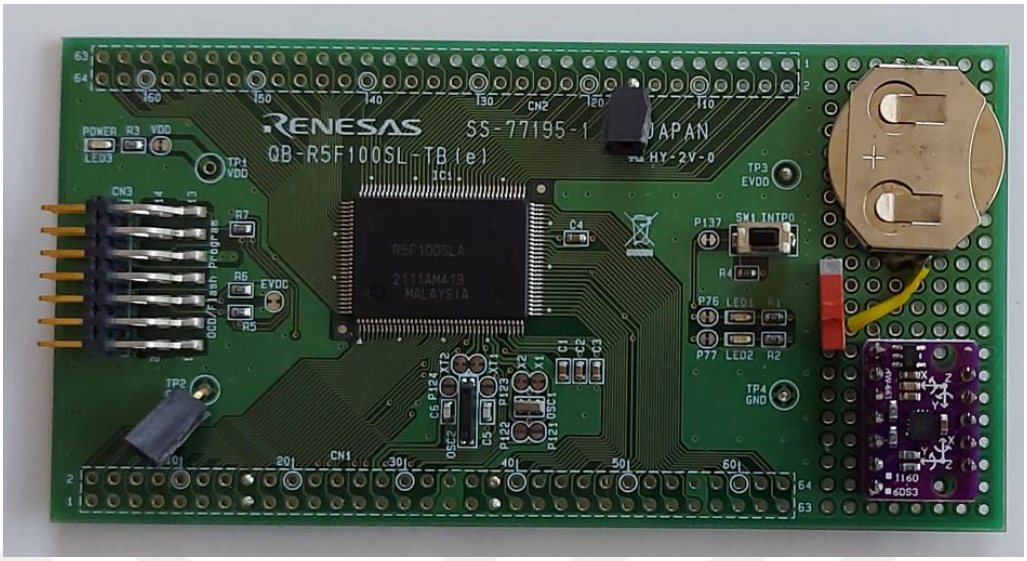
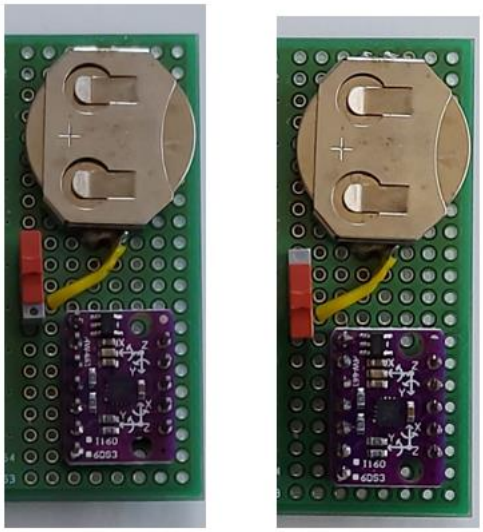


Figure *4* Experimental setup on Renesas RL78/G13 series target board

The purpose of using a slide switch is to select the power supply of the microcontroller and the Bmi160 sensor module. When the slide switch is in the position shown in Figure 5 (a), the development board is powered by the battery. When the slide switch is in the position shown in Figure 5 (b), the battery is disconnected, and the development board needs an external power supply.



(a) (b)

Figure *5* Slide switch for power supply selection

The external power supply is only used when downloading firmware on the board or when debugging is required.

2.2.1 Renesas R5F100SLA microcontroller

Features of this microcontroller: True low-power platform (66 µA/MHz, and 0.57 µA for operation with only RTC and LVD) for general-purpose applications, with 1.6-V to 5.5-V operation, 512-Kbyte code flash memory, 8-Kbyte data flash memory, 32-Kbyte Ram, and 41 DMIPS at 32 MHz.

It has 3 low power modes:

- HALT mode
- STOP mode
- SNOOZE mode.

In the first column of Table 1, the power consumption of the selected microcontroller is included, while in the other column, the power consumption of another microcontroller that can operate at low power is shown for comparison purposes.

Table 1 Power consumption comparison of microcontrollers

R5F100SLA	STM32L051C6
Renesas RL78/G13	Arm Cortex-M0+
CPU: 66 µA/MHz (Run mod) CPU: 0,23 µA (Sleep mod)	CPU: 88 µA/MHz (Run mod) CPU: 0,27 µA (Sleep mod)

2.2.2 Bosch BMI160 module

Bosch BMI160 is a low-power inertial measurement unit (IMU) that offers accelerometer and gyroscope in a single case. In our thesis project, we used a module with BMI160 as seen in Figure 6.

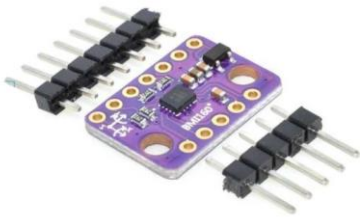


Figure *6* BMI160 accelerometer and gyroscope module

BMI160 supports both I²C and SPI to communicate with the microcontroller. We used I²C in the thesis.

The most important reason for choosing the BMI160 is its low-power operation, as in the selection of the microcontroller.

Chapter 3 - IMPLEMENTATION

We can consider the implementation part under four main headings. The first one is Embedded Software Development using e2 Studio, where we implement embedded software development on the electronic circuit side. The second one is Data Collection using Python, the program in which the data sent from the electronic circuit is transferred to the computer environment, and graphics are drawn. The third one is Machine Learning Implementation using MATLAB. The last one is Low Power Fall Detection.

3.1 Embedded Software Development using e2 studio

The microcontroller used in the thesis is produced by Renesas Company. Renesas Company also provides the development environment and compiler free of charge. e2 Studio is an Eclipse-based and easy-to-use IDE.

There are 3 different perspectives on the user interface.

- C / C++
- Code Generator
- Debug

The first of these is the C / C++ perspective, the part where the code is written. The second perspective, the Code generator, is very useful for the developer. When it is required to make the necessary settings with a visual interface to use any selected peripheral of the microcontroller, the Code Generator perspective is switched. The communication between the MCU and the accelerometer/gyroscope module was done via the I2C peripheral. To establish this communication, settings are made as shown in Figure 7 in the perspective of the Code Generator and the Generate Code button is clicked.

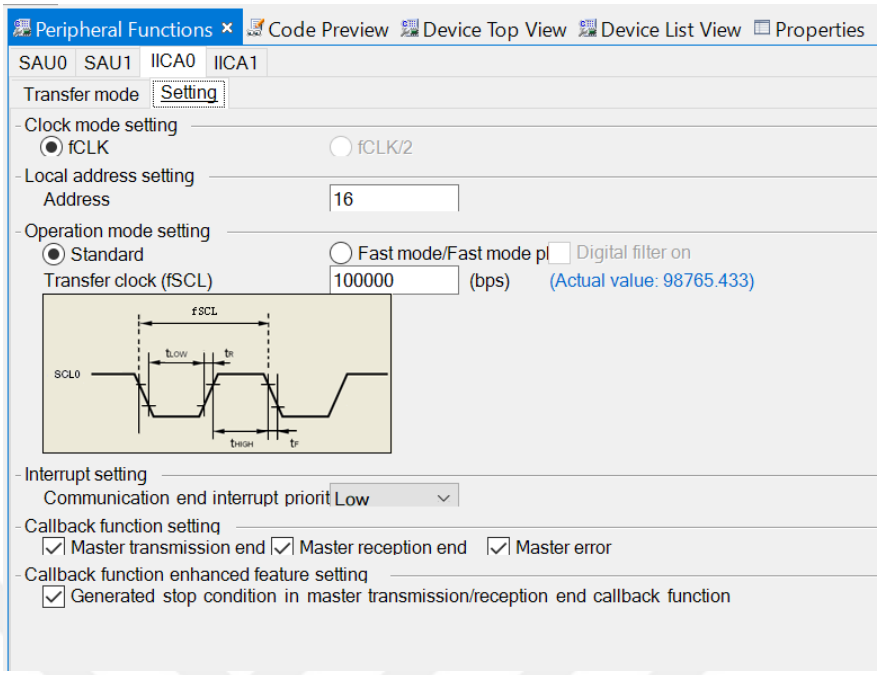


Figure *7* Code Generator settings

After clicking the Generate code button, three new files appear under the source folder. These are the header file, C file, and interrupt file of the relevant peripheral. We use peripheral-specific functions such as enable, disable, create, start, and stop in these files effectively in our code.

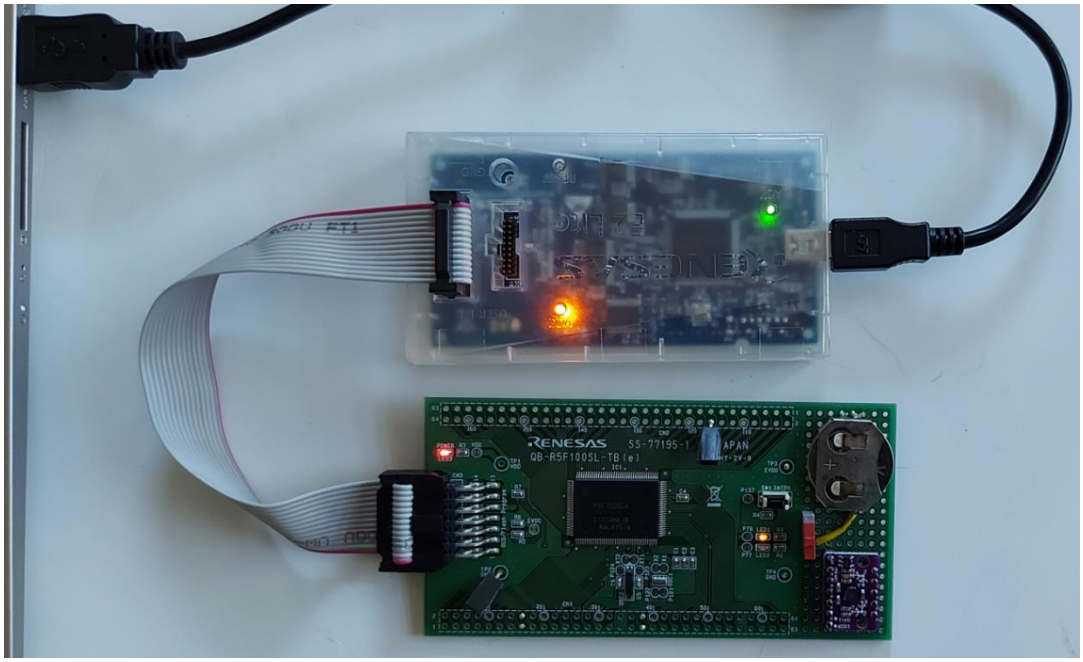


Figure *8* e2-Lite Debugger

Program downloading to the microcontroller is performed using the e2-Lite Debugger seen in Figure 8. e2-Lite Debugger is produced by Renesas company. This debugger allows the source code to be run step by step during the development phase of the project, or to put a breakpoint at a certain point in the source code and run it until that point and pause it.

3.2 Data Collection using Python

Python was used in this thesis to collect data and plot graphs. First, the battery is activated by turning the slide switch to the ON position. LED1 starts flashing. Then the button on the board is pressed. When the button is pressed, LED1 lights up instead of flashing. LED2 lights up 2 seconds after the button is pressed. From this point on, the microcontroller uses the I2C peripheral to take a ten-millisecond sample from the accelerometer and gyroscope module and reads the data for a total of three seconds. When the 3-second communication between the microcontroller and the module is completed, LED2 turns off, and LED1 continues to light up. Now the data to be transferred to the computer is in the RAM of the microcontroller. These data are transferred to the computer via the TTL to USB converter seen in Figure 9.



Figure *9* TTL to USB Converter

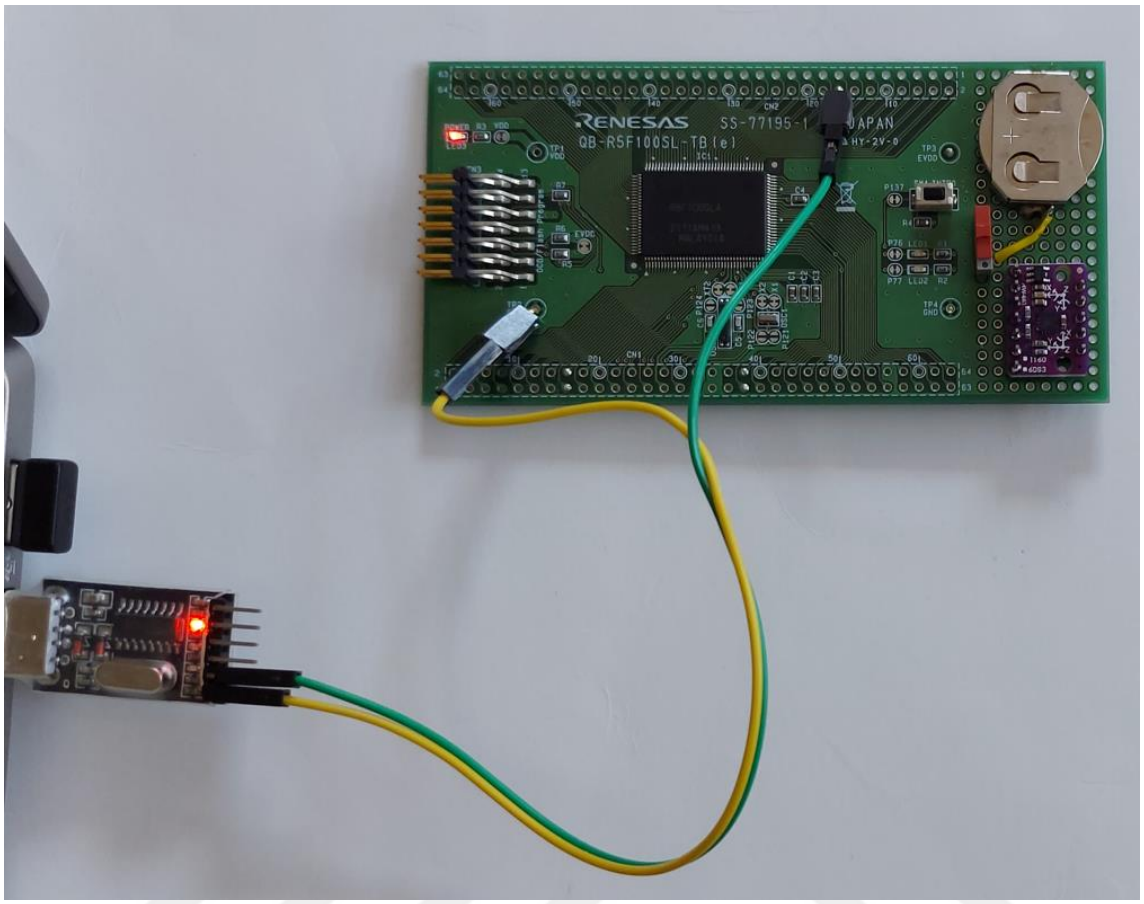


Figure *10* Data transfer from board to computer

Connection is made using the UART peripheral. As shown in Figure10, only TxD and GND connections are made. The data transferred from the board to the computer are waiting to be completed as seen in Figure 11.

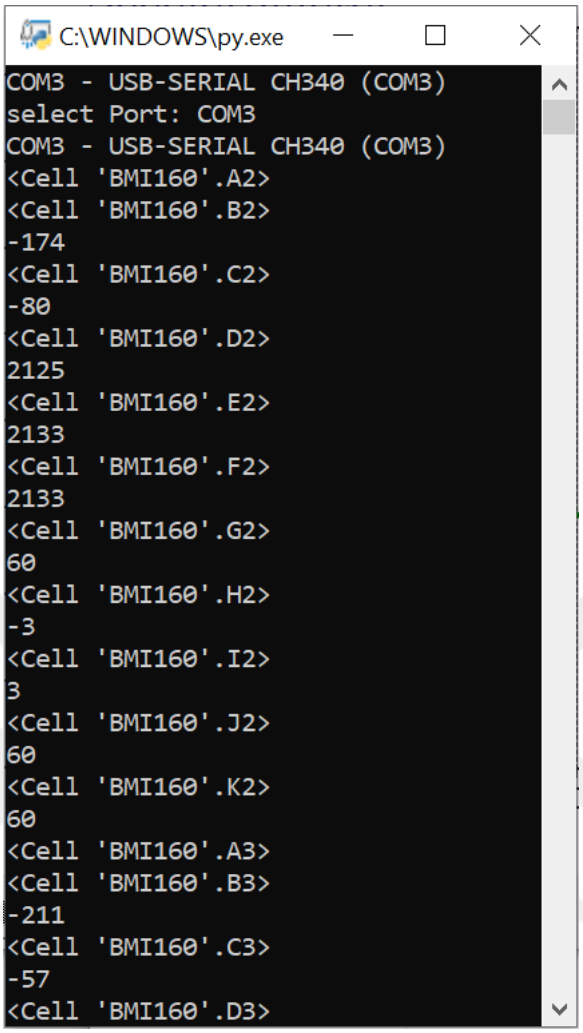


Figure *11* Data transfer monitoring screen

When the transfer is complete, the graph of the accelerometer and gyroscope data is drawn on the screen, as seen in Figure 12 and Figure 13, respectively.

Shown in blue in these graphs is the magnitude of samples taken every ten milliseconds. Shown in green is the 100-millisecond average of the magnitude.

These graphs show visually the time at which the falling moment occurred. Charts were created as a result of only one recording. Dozens of these records are brought together to form a database. Thus, it will be possible to use this database to use machine learning algorithms.

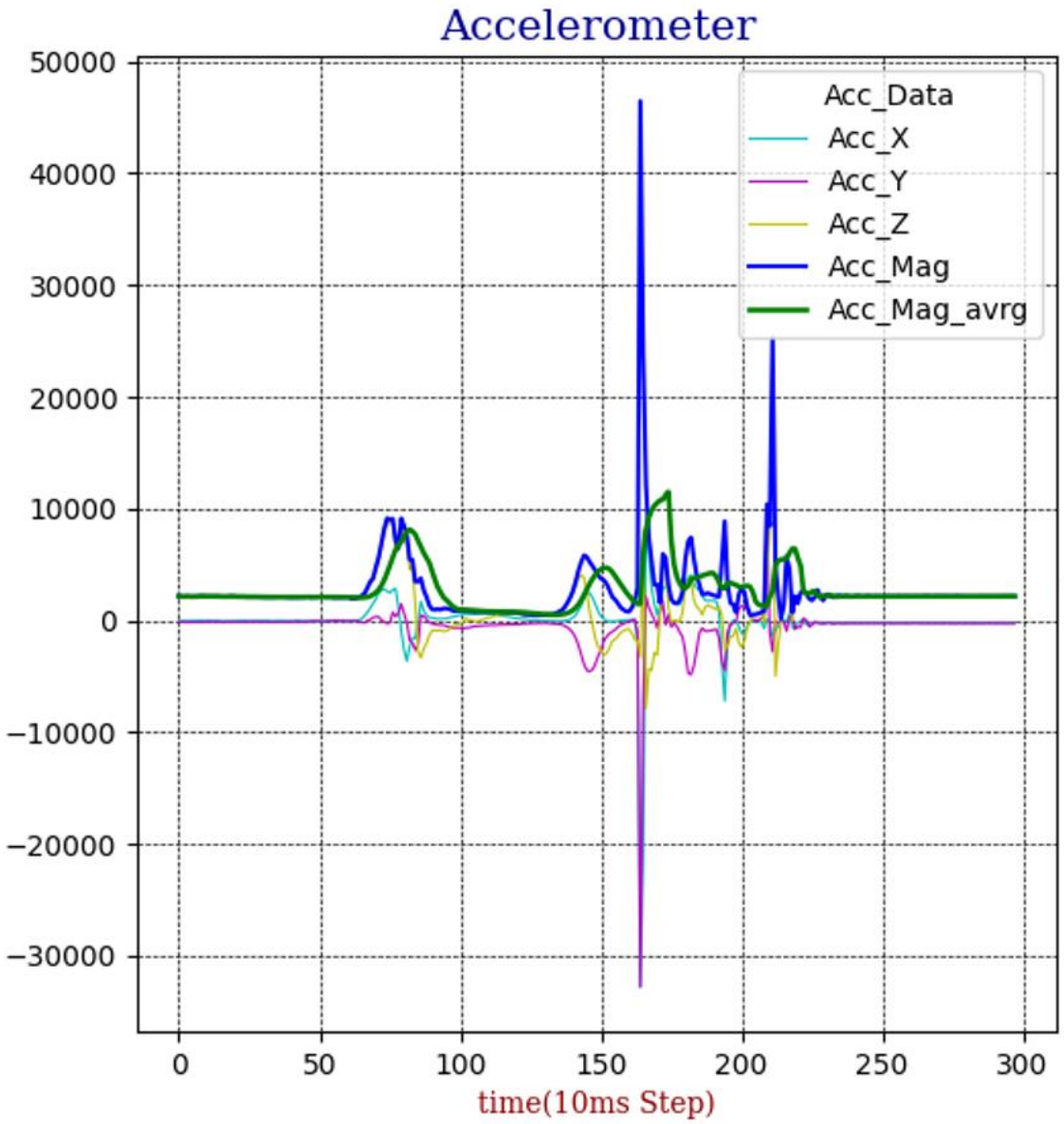


Figure ***12*** Accelerometer graphic.

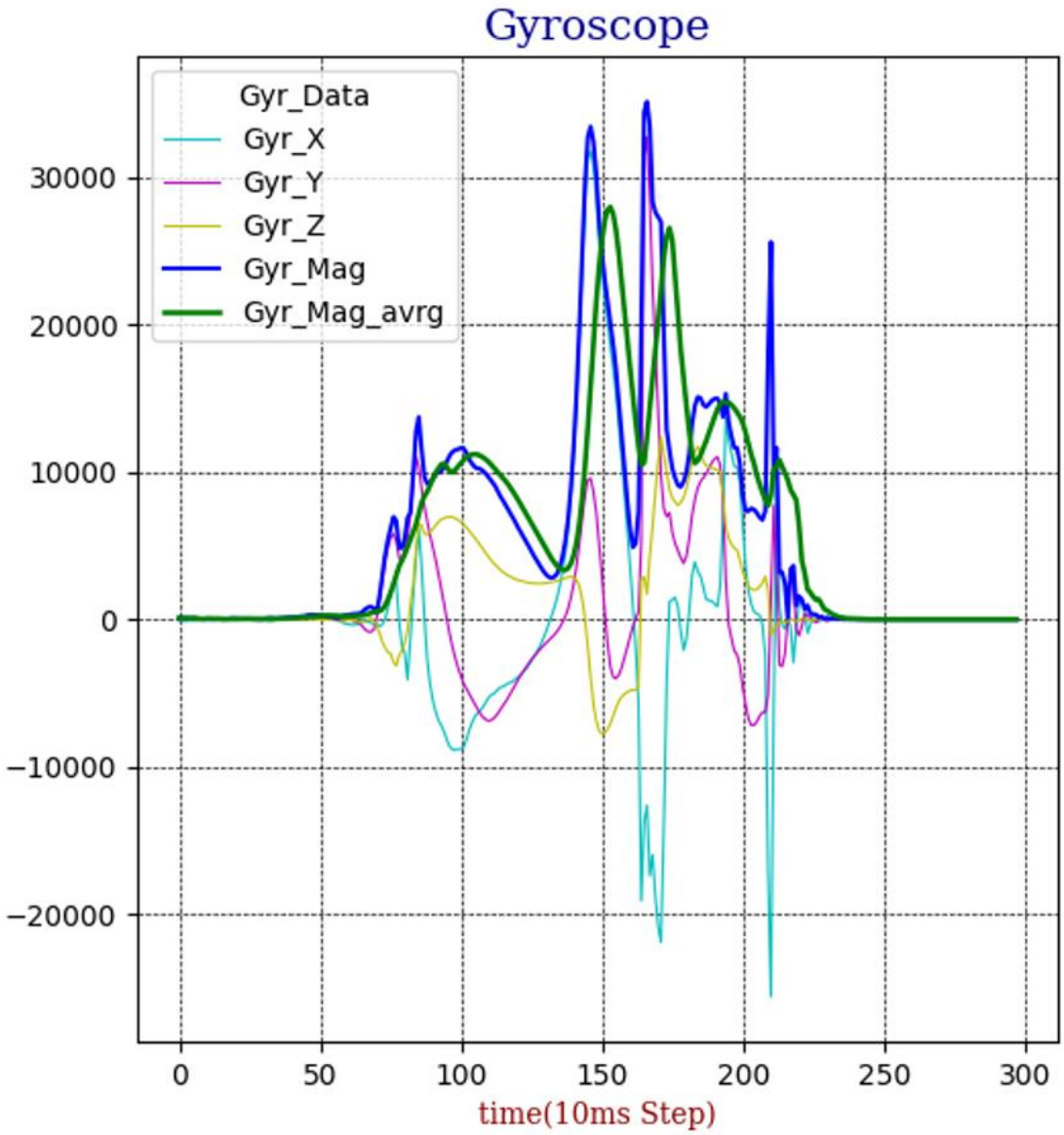


Figure *13* Gyroscope graphic.

3.3 Machine Learning Implementation using MATLAB

The peak value of the moving filtered vector magnitudes, indicated by the green line in Figure 12 and Figure 13, was used to classify. The scatter plot of many samples showing these peak values is shown in Figure 14.

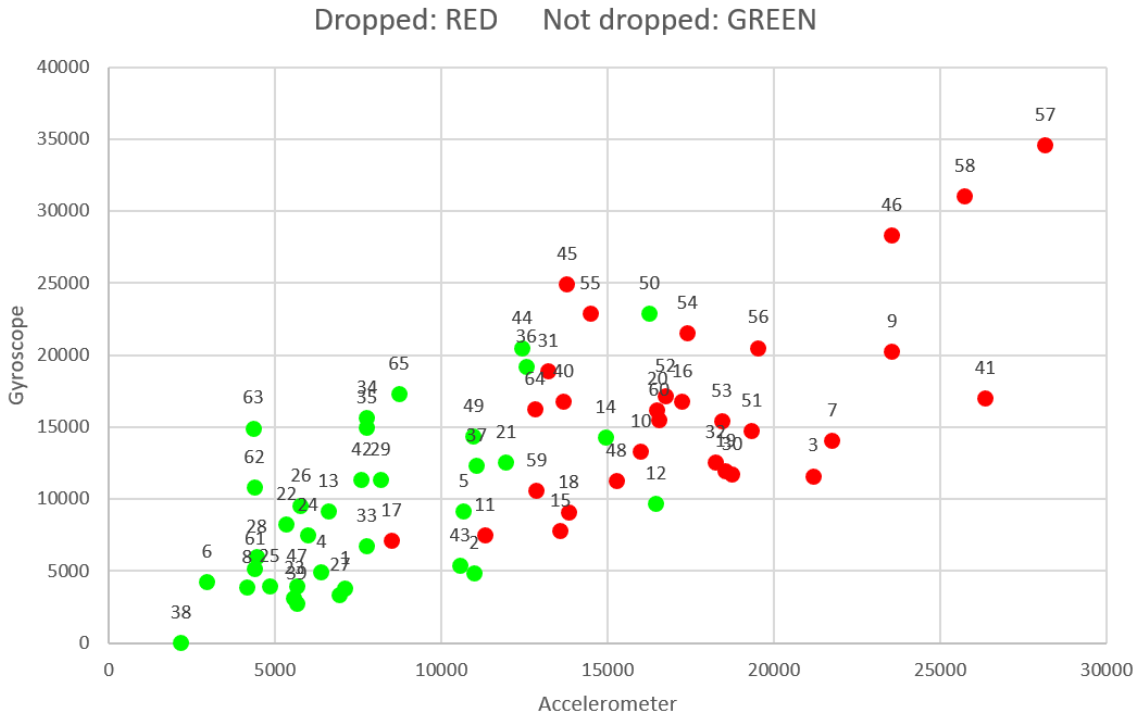


Figure *14* Scatter plot of samples.

In the graph shown in Figure 14, the projection of each red or green dot on the x and y axes shows the peak values measured from the accelerometer and gyroscope within three seconds of recording. Green dots indicate that the box mounted on the device did not fall during the test. Red dots indicate that the box has dropped. As seen in Figure 14, while the green dots are concentrated in one region, the red dots are scattered in the rest. Our goal is to determine the boundary line between the two regions and decide whether the package has dropped or not.

To determine the decision boundary line, it is necessary to choose the appropriate method among the machine learning algorithms. Since the output of our function will be 1 (dropped) or 0 (not dropped), binary classification is required. In this case, the appropriate machine learning algorithm would be "Logistic Regression".

$$\theta^T x = \theta_0 x_0 + \theta_1 x_1 + \theta_2 x_2 \qquad (3)$$

Equation 3 is the equation of the line we need to decide the boundary. The coefficients are found with the Logistic Regression algorithm using MATLAB functions in this equation. x_0 is constant, x_1 is accelerometer data, and x_2 is gyroscope data. θ_0, θ_1 and

θ_2 are the coefficients that must be found to determine the boundary line. Equation 4 shows the Logistic Regression hypothesis function.

$$h_\theta(x) = g(\theta^T x) \tag{4}$$

The g function in this equation is the sigmoid function. Equation 5 shows the sigmoid function.

$$g(\mathrm{z}) = \frac{1}{1+e^{-z}} \tag{5}$$

For logistic regression, cost function and gradient must be found. To find these values, the scatter plot shown in Figure 14 must first be normalized. Normalization is required because the accelerometer and gyroscope values are too large. Therefore, convex optimization becomes difficult to converge.

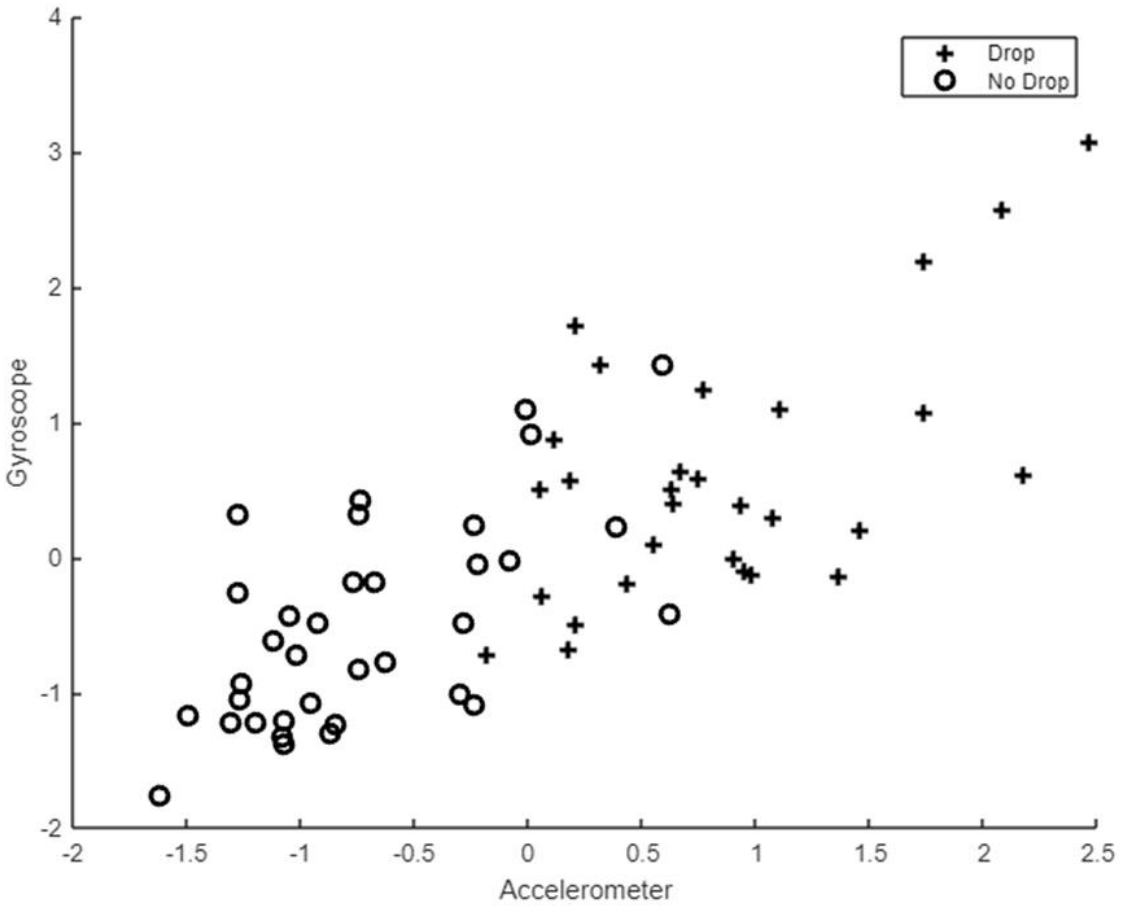


Figure *15* Normalized scatter plot of samples.

Averages and standard deviations of accelerometer and gyroscope values are calculated to obtain the scatter plot in Figure 15, which is created with normalized values. Then, for each point, the average of all accelerometer values is subtracted from the accelerometer value and divided by the standard deviation of all accelerometer values. The value found gives the value on the horizontal axis of the normalized scatter plot in Figure 15. To find the normalized value of the same point on the vertical axis, subtract the average of all gyroscope values from the gyroscope value of the relevant point and divide by the standard deviation of all gyroscope values.

After obtaining the normalized scatter plot, the lowest value of the cost function shown in Equation 6 is found using this data set.

$$J(\theta) = \frac{1}{m}\sum_{i=1}^{m}[-y^{(i)}\log\left(h_\theta\left(x^{(i)}\right)\right) - (1-y^{(i)})\log\left(1-h_\theta\left(x^{(i)}\right)\right)] \tag{6}$$

The values of θ_0, θ_1 and θ_2 obtained when the cost function is at its minimum value allow the determination of the decision boundary shown in Figure 16. These values are also used in embedded software. In this way, the microcontroller on the device decides whether the box has fallen by the decision boundary shown in Figure 16. It is enough to press the button on the device to see the result. If the box has not fallen, the green led lights up when the button is pressed. If it is dropped, the red led lights up when the button is pressed.

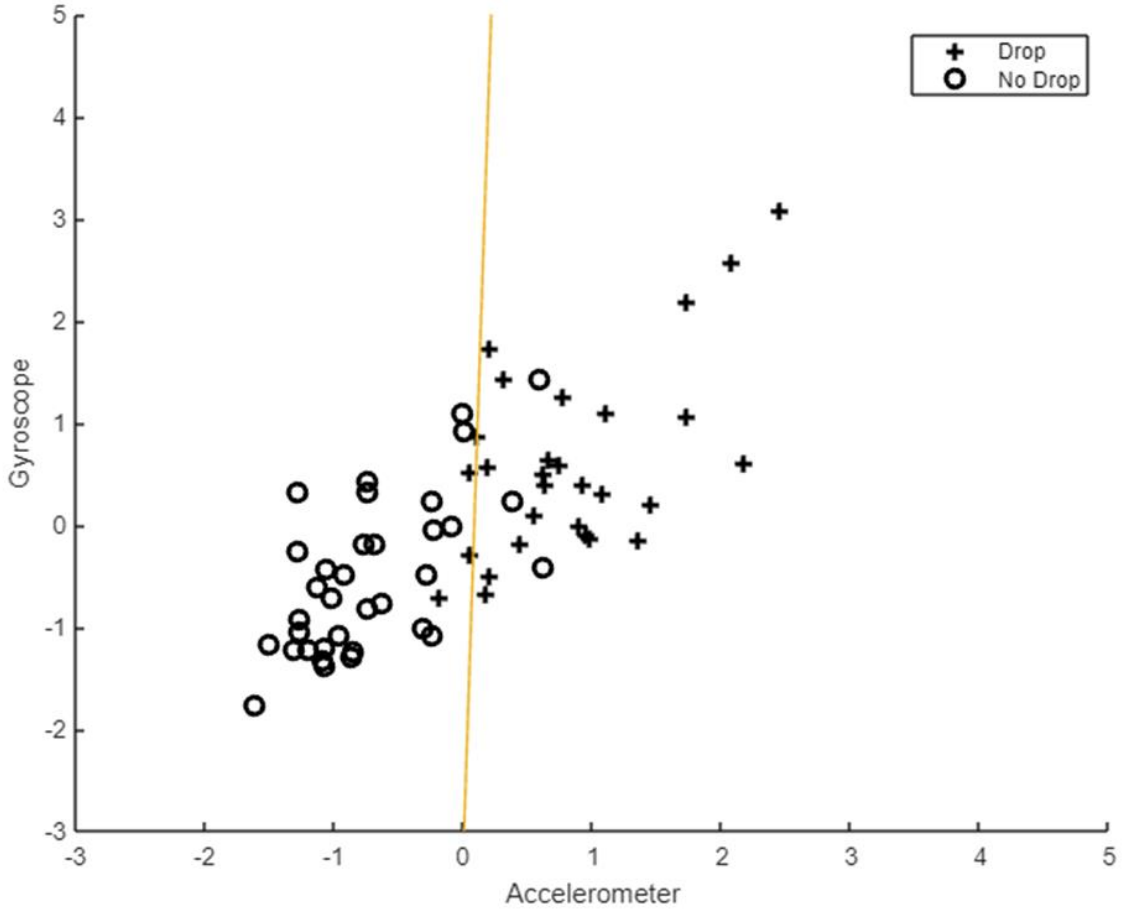


Figure *16* Decision Boundary.

3.4 Low Power Fall Detection Device

In addition to the firmware change for the device to operate at low power, some hardware changes were also made on the target board shown in Figure 4. First, LED 3, which indicates that there is energy on the board, is removed. In this way, an extra current is prevented from being drawn from the battery. In addition, the linear voltage regulator on the BMI160 module has been removed. In addition, the linear voltage regulator on the BMI160 module has been removed. Because even though no voltage is applied to the input of the voltage regulator when the internal structure of the regulator is examined, there was an extra 70 microamperes leakage current due to the feedback resistor divider at the output. After eliminating this leakage current, the required current values became measurable. Other changes made in the hardware are removing the orange LED 1 and

LED 2, replacing LED 1 with a red LED, and LED 2 with a green LED, and changing the resistors connected to the cathode of the LEDs for brightness adjustment.

The fall detection device keeps the microcontroller in sleep mode when there is no vibration or when it is exposed to vibrations that will not exceed a certain threshold value. In this case, the current drawn by the microcontroller from the battery is only 0.23 μA. At the same time, the BMI160 accelerometer and gyroscope module are also put into sleep mode for low-power operation. In sleep mode, the gyroscope is disabled. Only the accelerometer consumes 20 μA of current. When the acceleration difference is measured above a certain threshold value, the interrupt signal produced by the BMI160 causes the microcontroller to return to the normal operating mode from sleep mode. In this case, the microcontroller sends the necessary commands to the BMI160 IC over the I2C communication line and enables the gyroscope to work. From this point on, the accelerometer and gyroscope data read from the sensor for three seconds at 10-millisecond intervals are evaluated by the decision limit shown in Figure 16. During normal operation, the current drawn from the battery is 2.6 milliamperes. If the measured values fall below a certain threshold value within three seconds, it is switched to sleep mode again. With this method of operation, the fall detection device can be used repeatedly for a long time without the need for battery replacement.

Chapter 4 - NUMERICAL RESULTS

We can consider this part under four main headings. The first one is the dataset obtained by data collection. The second one is a detailed analysis of any two samples from the dataset. The third one is training and test accuracy. The last one is current consumption in sleep mode and run mode.

4.1 The Dataset obtained by data collection

The dataset required for logistic regression is shown in Table 2. The first column of this table indicates the sample number. The next two columns show the moving filtered peak values of the accelerometer and gyroscope during the three-second recording. The next column shows whether the board or the board affixed to the box fell as a result of this three-second recording. The last column contains a description of the event that took place during the three-second recording.

Table 2 Dataset obtained by data collection

No	Acc. peak	Gyro. peak	Drop or Not	Event explanation
1	7110	3789	NO	I held the box in my hand and shook it so that it remained level from the ground. I did not change the orientation of the box. With the card facing up…
2	10984	4842	NO	I held the box in my hand and shook it so that it remained level from the ground. I did not change the orientation of the board with the card facing down.
3	21181	11597	YES	I let the box free fall from 1 meter. Without turning the tile fell to the floor. On the top surface of the card box...
4	6395	4915	NO	I threw the box about 1 meter up and held it. The card was on the top surface of the box. The box did not turn over.
5	10675	9166	NO	I threw the box about 1 meter up and held it. The box rotated 360 degrees once while coming down from the top.

6	2950	4272	NO	I held the box from the table with both hands. Then I quickly took it under my left arm. The card remained on the top surface of the box.
7	21756	14075	YES	I dropped the box from 1 meter high. It rotated 360 degrees as it fell. The card was initially on the upper surface. After falling, it remained on the upper surface.
8	4156	3855	NO	I took the box from the table and turned it 90 degrees and put it on the shelf 1.5 meters above the floor.
9	23554	20263	YES	The box fell from a height of 2 meters. Even though the sensor board started to fall facing up, it was rotated 90 degrees from its starting position when it landed on the carpet.
10	16001	13311	YES	The box fell from a height of 1 meter, spinning down. Although the sensor board started to fall with its face up, it was rotated 90 degrees from its starting position when it fell to the ground.
11	11305	7502	YES	The box fell from half a meter, turning 90 degrees. So, when the card was facing up, its direction changed to 90 degrees.
12	16453	9651	NO	Holding the box in my hand, I spun around very quickly.
13	6600	9138	NO	The box was on the table. Sitting on the bench, I took the box from the table with one hand and quickly handed it to someone behind me. The box quickly completed a circular rotation of about 150 degrees.
14	14936	14282	NO	I did the same as sample 13. But as I turned my arm back, I also turned the box down 90 degrees with my wrist.
15	13582	7806	YES	With the sensor board facing up, the box fell off the table to the floor. The sensor board hit the floor as the box flipped down as it fell.
16	17244	16775	YES	With the sensor board facing up, I pushed the box horizontally from the bench. The box fell about 3 meters ahead. While the box was in the air, it spun around with the card face up.
17	8498	7103	YES	Sitting on the bench, with the sensor board facing up, the fall distance is only 25 cm. Box and card rotated 90 degrees.
18	13824	9043	YES	Sitting on the bench, with the sensor board facing up, the fall distance is only 25 cm. The box did not rotate. It skipped an inch or two.

19	18550	11907	YES	It felt free from the chandelier level (from a height of 2 meters) The card never changed its up position.
20	16492	16200	YES	It felt free from the chandelier level (from a height of 2 meters) The card fell, facing right, without changing its position.
21	11941	12507	NO	I threw the box up. After rotating the box, a couple of times, I held the box.
22	5341	8224	NO	I took the box off the table and opened my arm to the left.
23	5580	3116	NO	I took the box from the table and put it back on the table 50 cm to the side. I rotated it 90 degrees while putting it on the table.
24	5981	7482	NO	I caught the box as it fell from the table.
25	4830	3940	NO	I pushed the box onto the table. The box slipped 1.5 meters. But it did not fall off the table.
26	5774	9527	NO	I took the box from the table and opened my left arm and rotated the box 180 degrees.
27	6951	3350	NO	I bent down and picked up the box lying on the floor and raised it to my chest.
28	4442	5969	NO	I bent down and picked up the box lying on the floor and raised it to waist height. Meanwhile, I rotated the box 90 degrees.
29	8164	11353	NO	I bent down and picked up the box from the floor and raised it as fast as I could to chest level. Meanwhile, I rotated the box around 120 degrees.
30	18742	11699	YES	I bent down to pick up the box lying on the floor and dropped it before it reached waist level. While falling, the box turned 180 degrees and crashed into the carpet, leaving the card under the box.
31	13207	18860	YES	I was standing with the box in my hand. I threw the box at the curtain about 3 meters away. The box slammed into the curtain and fell onto the seat.
32	18242	12564	YES	I was standing with the box in hand. I threw the box toward the wall from about 2.5 meters. The box hit the wall and fell on the door. Then he slid slowly between the door and the wall, landing on the floor.
33	7755	6744	NO	I lifted the box on the carpet with both hands and rotated it 90 degrees and put it on the shelf 2 meters high.

34	7766	15643	NO	The card flipped upside down 90 degrees from the table to the chair cushion in the kitchen. Of course, we do not consider it as a fall because it is a very short distance. (Board only)
35	7757	14940	NO	The card flipped upside down 180 degrees from the table to the chair cushion in the kitchen. Of course, we do not consider it as a fall because it is a very short distance. (Board only)
36	12552	19190	NO	Table to the bench (board only)
37	11057	12319	NO	Table to the bench (board only)
38	2169	10	NO	Stationary (board only)
39	5647	2745	NO	Vibration (board only)
40	13669	16747	YES	Free fall (1.5-meter-high). As soon as it starts to fall, the card is turned (board only)
41	26352	16977	YES	Free fall on the carpet from 1.5 meters. The card did not rotate when the free fall started. The card was rotated at the last moment. (Board only)
42	7602	11307	NO	I threw the card about 1 meter up and held it. The card was rotated once or twice (board only)
43	10558	5403	NO	Sitting on the bench, I tossed the card up about 50cm and held it. The card is not rotated. (Board only)
44	12426	20439	NO	I got on the chair. I threw the card. A person sitting in the other seat held the card I had thrown. The distance between us is about 2 meters. (Board only)
45	13783	24922	YES	While standing, I threw the card on the sofa from 2 meters. The card hit the sofa and fell on the carpet. (Board only)
46	23541	28300	YES	I threw the box quickly towards the point where the two walls meet, by rotating the box. The distance between them was about 4 meters. The box hit the wall and fell on the chair.
47	5651	3964	NO	I slowly placed the box on the treadmill. The treadmill was set to the slowest speed on stage one.
48	15257	11283	YES	I slowly placed the box on the treadmill. The treadmill was set to the highest speed at the twelfth level. At the end of the treadmill, the box stopped hitting the radiator at a distance of 50 cm.
49	10971	14323	NO	While we were both standing and there was a distance of about 5 meters between us, I threw the box and another person held the box. The box was rotated once.

50	16254	22847	NO	While sitting on the chair, I threw the box about 1 meter up and held it. The box rotated several times.
51	19335	14751	YES	Like throwing a stone, I threw the box at the curtain. The distance was around 4 meters. As the box crashed into the curtain and fell, it got stuck between the armchair and the wall.
52	16740	17161	YES	I threw the box 1 meter up. After the free fall started, he hit the treadmill 3 meters below. The treadmill was at its fastest setting at the time of the impact.
53	18430	15423	YES	Standing, I threw the box upside down so that it slammed into the ceiling of the room. The box crashed into the ceiling and landed upside down on the carpet.
54	17396	21549	YES	I was standing. I threw the box by rotating it upwards. The box hit the ceiling of the room, fell on the carpet and rotated.
55	14477	22850	YES	I stood in the hallway and threw the box six meters ahead. I rotated the box as much as possible while throwing it.
56	19529	20500	YES	While standing, I dropped the box from 1.7 meters above. I left the box to let it rotate a few turns as I dropped it.
57	28162	34594	YES	Standing, I threw the box fast enough to slam it into the ceiling. I took it out of my hand so that it would rotate the box many times while throwing it. The box crashed into the sofa as it fell. Then the box did somersaults on the carpet a couple of times.
58	25740	31000	YES	While sitting on the chair, I rotated the box as much as possible and threw it 50 cm up. The box crashed into the chair as it fell.
59	12866	10566	YES	I left the box at a distance of 1.5 meters. Since I left the box upright, the card fell to the side rather than up.
60	16543	15449	YES	I left the box at a distance of 1.5 meters. Since I left the box upright, the card fell to the side, not up, and stood with the card face down.
61	4394	5146	NO	The box was on the table. I rotated the box 90 degrees without moving the box away from the table.
62	4373	10809	NO	The box was on the table. Without moving the box away from the table, I quickly rotated the box 270 degrees and left it on the table.

63	4342	14917	NO	I took the box between my two hands and shook it. Then I rotated it 90 degrees.
64	12812	16272	YES	I threw the box up without rotating it. It went up about 1 meter and fell about 3 meters down. It only rotated 90 degrees while falling.
65	8721	17327	NO	I had the box on the table rotated left and right as fast as I could with the flick of my wrist.

4.2 Detailed analysis of any two samples from the dataset

This section includes a detailed analysis of any two samples listed in Table 2. Looking at record 61, the box was on the table. I rotated the box 90 degrees without moving the box away from the table. The graphics of this record are shown in Figure 17.

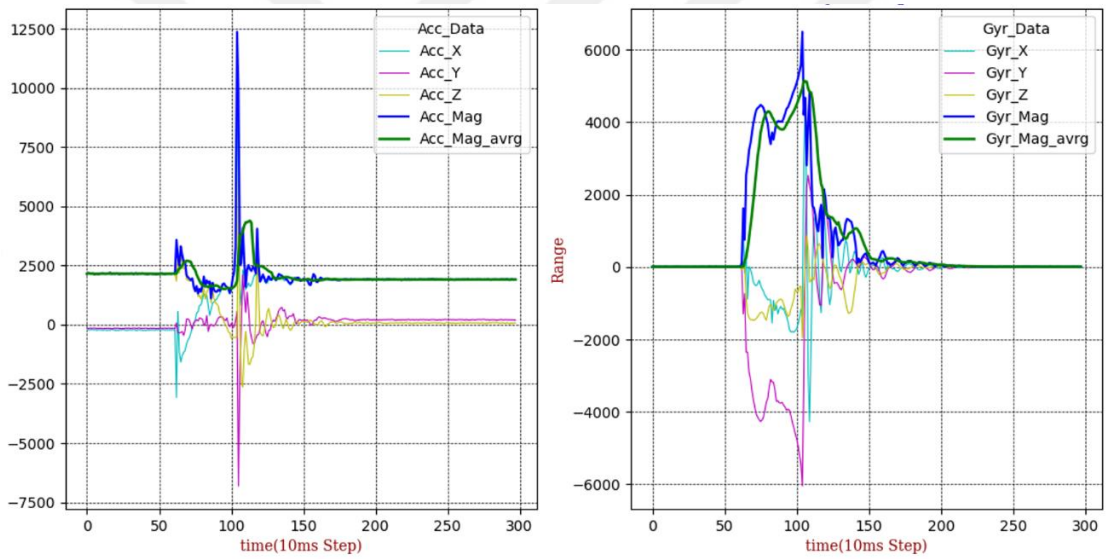


Figure *17* Sample registered as not dropped

Looking at record 9, the box fell from a height of 2 meters. Even though the sensor board started to fall facing up, it was rotated 90 degrees from its starting position when it landed on the carpet. The graphics of this record are shown in Figure 18.

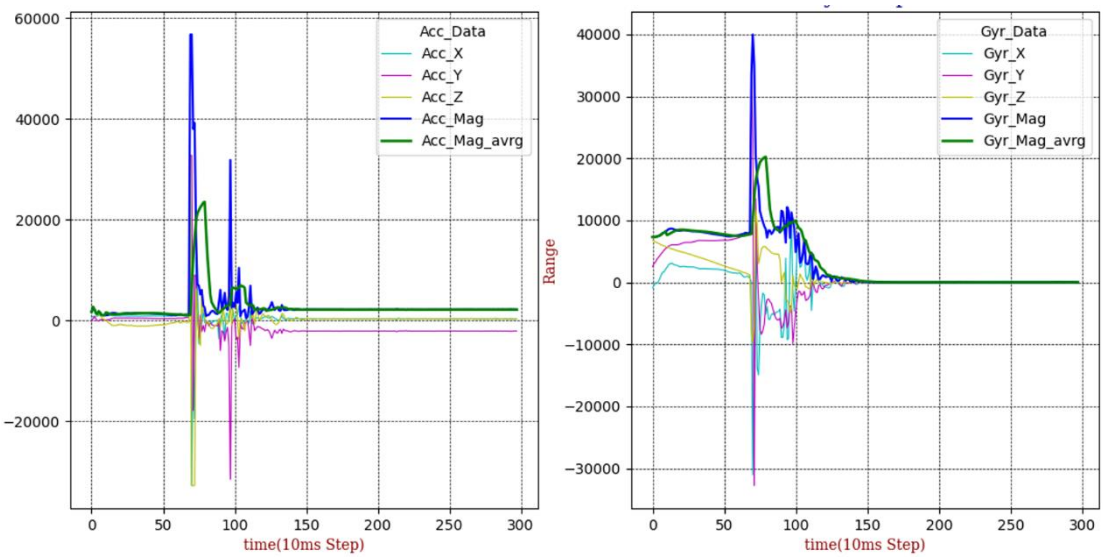


Figure *18* Sample registered as dropped

4.3 Train and Test Accuracy

When we reserve the first 40 rows of the samples in Table 2 for training and the rest for testing, the MATLAB output is shown in Figure 19.

```
Command Window
Plotting data with + indicating (y = 1) examples and o indicating (y = 0) examples.
Cost at initial theta (zeros): 0.693147
Gradient at initial theta (zeros):
 0.150000
 -0.368789
 -0.241297

Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
Cost at theta found by fminunc: 0.241124
theta:
 -1.512204
 3.675470
 0.004664
Train Accuracy: 90.000000
Test Accuracy: 88.000000
>>
```

Figure *19* Train and Test Accuracy

4.4 Current Consumptions in Sleep mode and Run mode

The device consumes around 20 microamperes in sleep mode. When it detects any movement and switches to run mode, it consumes 2.6 milliamperes of current. If no motion is detected above a certain threshold within three seconds, it will switch to sleep mode again. Measurements were made by connecting the measuring instrument in series between the battery and the electronic circuit as shown in Figure 20 and Figure 21.

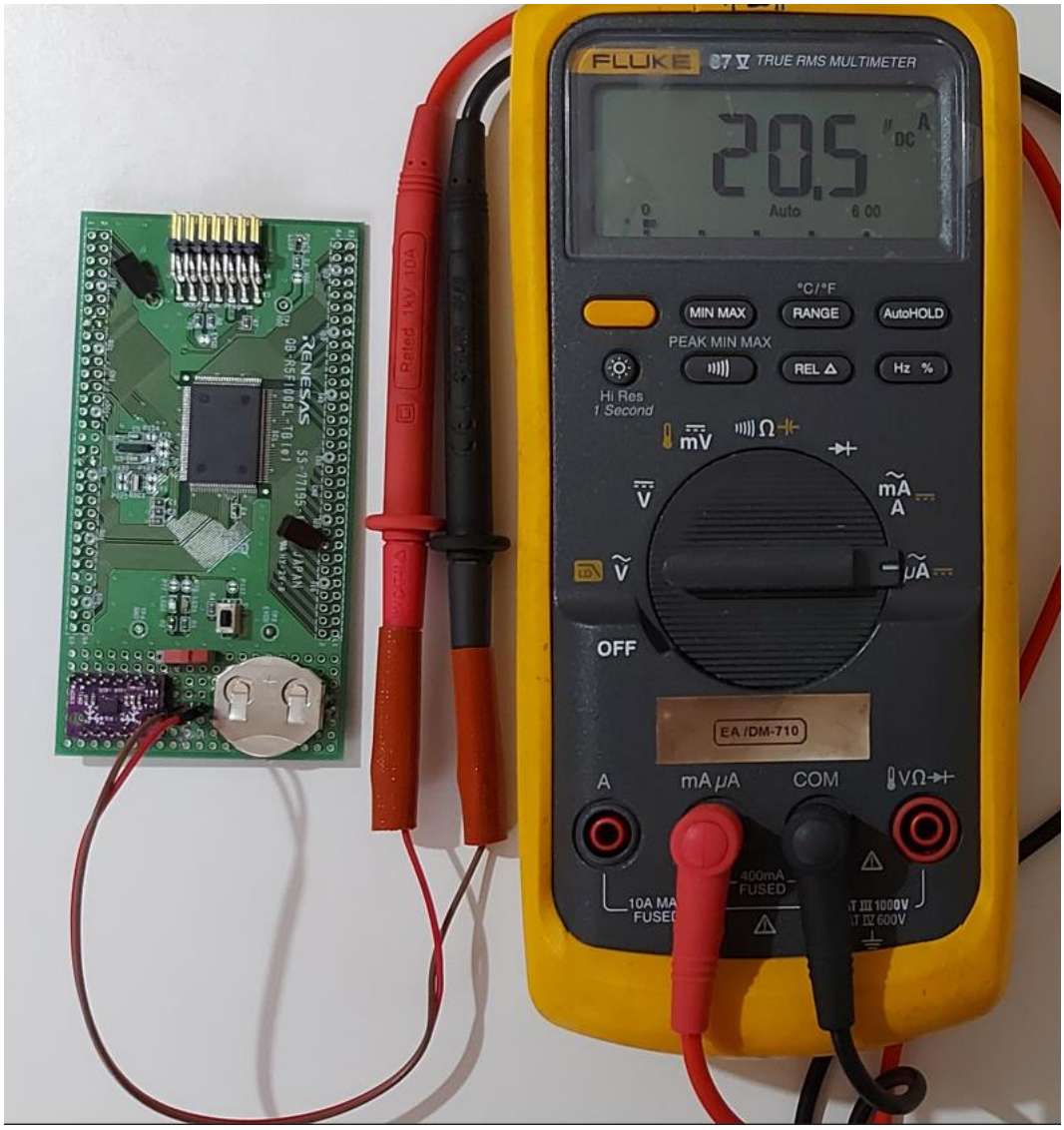


Figure *20* Current consumption in Sleep mode

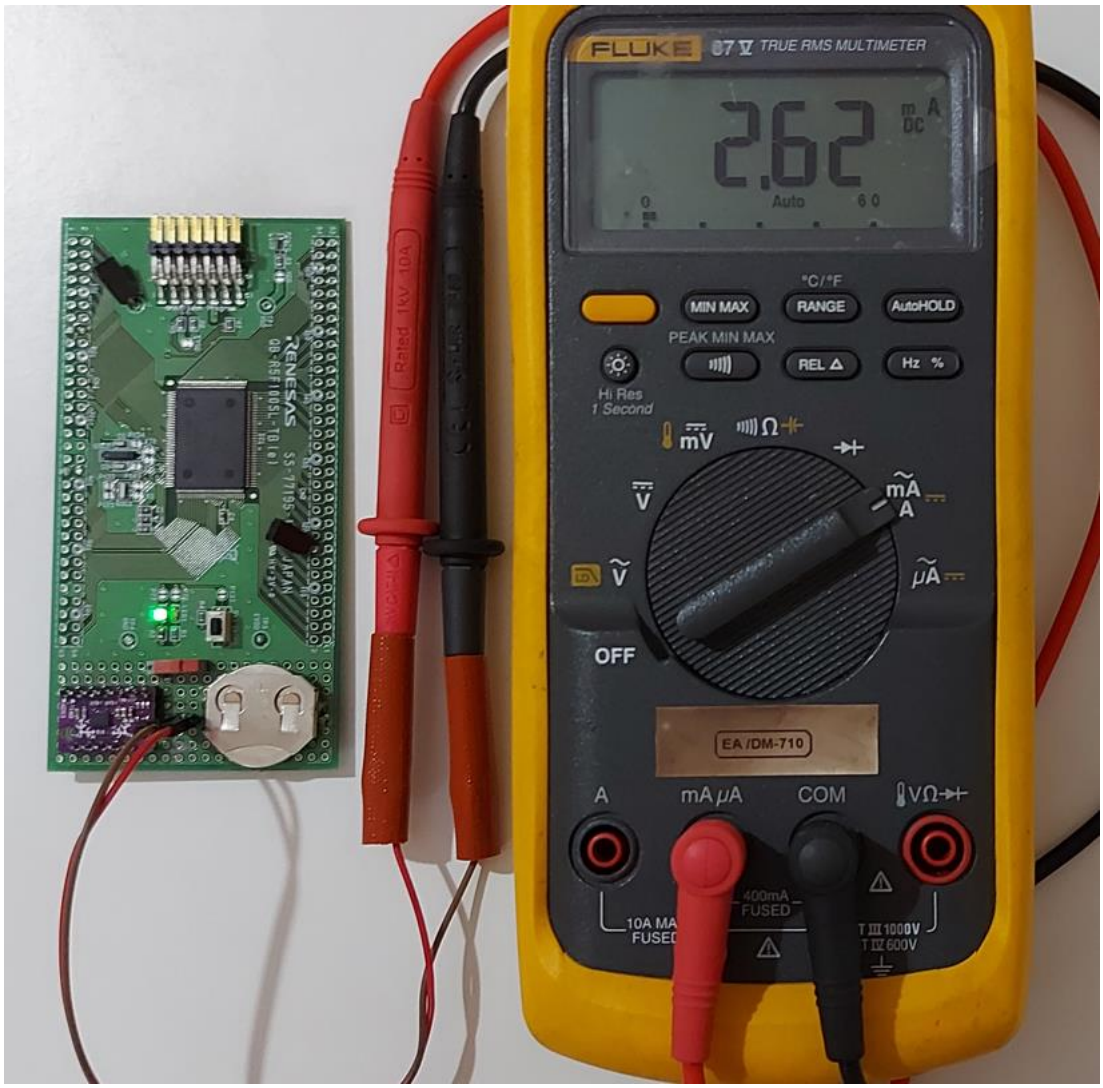


Figure *21* Current consumption in Run mode

Chapter 5 - CONCLUSIONS FUTURE RESEARCH DIRECTIONS

In this study, we proposed a thesis based on the rapid increase in the transaction volume in the field of e-commerce. With the effect of the pandemic, high-priced or fragile items started to be transported by cargo. Therefore, some logistical problems such as damage to the transported product are more common. There are fall detection algorithms in the literature. They usually use the accelerometer and gyroscope in these studies. The vast majority of studies so far have been done to detect the falling of the elderly and people in need of care. But unlike these studies, we look at the retail side and the transportation side. During the transportation of an ordered product, it is important to detect whether it is damaged or not. To collect the necessary data, we designed a low-power device, which includes a low-power microcontroller and an accelerometer, and gyroscope module. We determined the threshold values by transferring these data to the computer and drawing graphs.

The data set was prepared by transferring the test data to the computer. Using this dataset, a model was created with the Logistic Regression method, and this model was embedded in the microcontroller. The microcontroller embedded software can detect whether the cargo package has dropped using this model. In addition, the CPU is operated in sleep mode until an interrupt signal is received from the accelerometer and gyroscope sensor to the microcontroller. In this way, power consumption is reduced to a minimum, and battery life is extended.

In future studies, it is planned to add a different machine learning algorithm in addition to the Logistic Regression method. The purpose of the second model will be to avoid erroneous drop detections that rarely occur at points close to the decision boundary determined using Logistic Regression.

In addition, in the continuation of this work, software development will be made to further extend the battery life. This fall detection device keeps the microcontroller in sleep mode when there is no vibration or when it is exposed to vibrations that will not exceed a certain threshold value. In this case, the current drawn by the microcontroller from the battery is only 0.23 μA. At the same time, the BMI160 accelerometer and gyroscope module are also put into sleep mode for low-power operation. In sleep mode, the gyroscope is

disabled. Only the accelerometer consumes 20 µA of current. When the acceleration difference is measured above a certain threshold value, the interrupt signal produced by the BMI160 causes the microcontroller to return to the normal operating mode from sleep mode. In short, the device has two different operating modes, sleep mode, and run mode. In the next step, we will add a third mode of operation, which we will call deep sleep mode. If the CPU is not woken up by an interrupt from the BMI160 module for 1 hour while in sleep mode, it will go into deep sleep mode. When switching to deep sleep mode, a 5 µA current will be drawn from the battery instead of 20 µA. In this way, if the device does not detect any acceleration, the battery life will be quadrupled.

REFERENCES

Chang, W.-J., Chen, L.-B., & Su, J.-P. (2020). Design and Implementation of Intelligent Tape for Monitoring High-Price and Fragile Cargo Shipments During Transport Procedures. *IEEE Sensors Journal*.

Chen, Y., Du, R., Luo, K., & Xiao, Y. (2021). Fall detection system based on real-time pose estimation and SVM. *IEEE 2nd International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering.*

Guo, H. W., Hsieh, Y. T., Huang, Y. S., Chien, J. C., Haraikawa, K., & Shieh, J. S. (2015). A Threshold-based Algorithm of Fall Detection Using a Wearable Device with Tri-axial Accelerometer and Gyroscope. *ICIIBMS*, Signal Processing, Computer Networks and Telecommunications, Okinawa, Japan.

Huynh, Q., Nguyen, U., Irazabal, L., Ghassemian, N., & Tran, B. (2015). Optimization of an Accelerometer and Gyroscope-Based Fall. *Hindawi Publishing Corporation*, Journal of Sensors, Volume 2015, Article ID 452078, 8 pages.

Jefiza, A., Pramunanto, E., Boedinoegroho, H., & Purnomo, M. H. (2017). Fall Detection Based on Accelerometer and Gyroscope using Back Propagation. *4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI).*

Lan, C.-C., Hsueh, Y.-H., & Hu, R.-Y. (2012). Real-Time Fall Detecting System Using a Tri-axial Accelerometer for Home Care. *International Conference on Biomedical Engineering and Biotechnology.*

Rakhman, A. Z., Nugroho, L. E., Widyawan, & Kurnianingsih. (2014). Fall detection system using accelerometer and gyroscope based on smartphone. *The 1st International Conference on Information Technology, Computer, and Electrical Engineering.*

Rescio, G., Leone, A., & Siciliano, P. (2013). Support Vector Machine for Tri-axial Accelerometer-based Fall Detector. *5th IEEE International Workshop on Advances in Sensors and Interfaces IWASI.*

Sivaranjani, T., Lakshmi, L. D., Yogaaravinth, R., Srivishnu, J., Sri Karthick, M. M., & Praveenkumar, A. (2017). Fall Assessment and its Injury Prevention using a Wearable Airbag Technology. *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI).*

Sorvala, A., Alasaarela, E., Sorvoja, H., & Myllylä, R. (2012). A Two-Threshold Fall Detection Algorithm for Reducing False Alarms. *6th International Symposium on Medical Information & Communication Technology (ISMICT).*

Tan, T. D., & Tinh, N. V. (2014). Reliable Fall Detection System Using a 3-DOF Accelerometer and Cascade Posture Recognitions. *Signal and Information Processing Association Annual Summit and Conference (APSIPA), 2014 Asia-Pacific.*

CURRICULUM VITAE

Name Surname **:** Alper Tunga ERDOĞAN

Education:

Bachelor of Science

1997-2001 Eskişehir Osmangazi University
Faculty of Engineering and Architecture
Electrical and Electronics Engineering

Publications:

Conference Presentations: *Düşük Güçlü Gömülü bir Platformda Kargo Paketi Düşme Tespiti.* **Alper Tunga Erdoğan and Engin MAŞAZADE, ELECO, 2022.**