LEAK DETECTION IN PIPES THROUGH MECHANICAL VIBRATION ANALYSIS.

ABSTRACT

Leaks in pipe networks are a possible threat to public safety in addition to the problems with water quality and financial losses. To avoid structural damage and water losses, it is essential to identify water leaks in pipe networks as soon as possible. Due to its potential use in real-time monitoring systems for leak detection, the method of data collecting based on sensors embedded in pipeline networks has drawn a lot of attention. This thesis presents the design and implementation of a system for pipeline leak detection using mechanical vibration detection with an accelerometer sensor. The system includes a microcontroller unit for data acquisition and processing and a wireless communication module for remote monitoring. The accelerometer was calibrated and tested for sensitivity to leakage-induced vibrations. The system was then implemented and tested on a small-scale pipeline model, showing high accuracy in detecting leaks. The results demonstrate the feasibility of using mechanical vibration detection with an accelerometer for pipeline leak detection in industrial applications. The experiment shows the easiness of remote monitoring of pipelines for leakages. And this, I believe, will go a long way toward strengthening further research projects in Ghana's Water and Gas Company to facilitate leak detection.

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CHAPTER ONE

INTRODUCTION

1.1 Problem Statement

Water, oil, and gas are transported around the world through millions of kilometers of pipelines. Pipeline networks are very complex and growing all the time. This exposes them to many risks. Ducts are prone to cracking and loss of function due to internal and external corrosion, manufacturing defects, and third-party damage leading to leaks. On October 7, 2017, a massive explosion occurred at an LPG gas station near Madina Junction in Accra, Ghana. This resulted in seven deaths and 132 injuries. The cause was a leak in the gas station pipe and tank.

On March 3, 2022, the Ghana Water Company (GWLC) announced that it had failed to account for 40% of the water produced for consumption [9]. This percentage was the result of leaks, bursts, and illegal water connections. This poses a grave threat to the economic sustainability, environment, and human livelihoods of the country. The development of robust leak detection systems in pipelines is essential to contain this problem.

1.3 Objectives of the Project

1.3.1 General Objective

This project aims to design and implement an intelligent pipeline leak monitoring and detection system using mechanical vibration analysis and IOT technology.

1.3.2 Specific Objectives

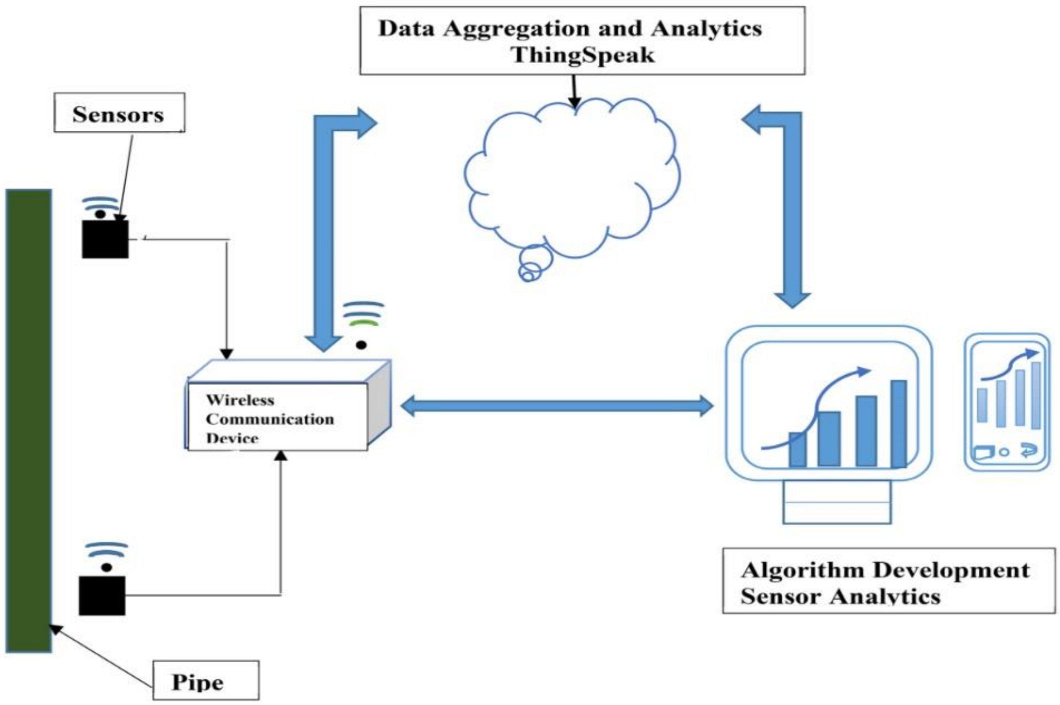
The specific objectives of this project are to:

- Measure pipeline mechanical vibrations for further analysis.
- Detect pipeline leaks.

❖ Provides real-time analytics to remote computers.

1.6 Brief Methodology

The project is implemented with acceleration transducers, a microcontroller board, a wireless communication device, a signal analysis algorithm, and an IOT technology. The acceleration traducers capture the surface vibration of the pipeline generated because of pressurized



fluctuations. This captured data is sampled by the microcontroller at a constant baud rate and sent to our signal analysis tool through our wireless communication device. The Signal analysis algorithm processes the sampled data into the frequency domain for effective analysis. The analyzed data from our signal analysis algorithm is displayed on our remote-based monitoring system. Our remote-based monitoring system is comprised of a web server and a web application Fig 1.5.1 shows the process flow diagram of our system implementation.

Figure 1.6 Methodology Diagram[1]

CHAPTER TWO

METHODOLOGY

2.1 Overview

This chapter discusses the research methodology encompassing the project design, research method, software selection and justification, basic system model, mathematical model, and computational algorithm analysis. Discrete components used in system modeling are also discussed in this chapter.

2.2 Project Design

The entirety of this project is aimed at designing a low-cost leak detection and monitoring system that can detect and monitor the presence of leaks in a pipeline structure.

The working principle of this project is based on frequency analysis of surface vibrations collected by the MPU6050 accelerometer sensor and analyzed through the use of the Discrete Fourier Transform.

2.3 Basic System Model

In this project, we interface the Esp8266 microcontroller and Arduino-Uno microcontroller with the MPU6050 accelerometer + gyroscope sensor. We utilized a software serial communication in establishing a connection between the Arduino and Esp8266. We used one MPU6050 accelerometer sensor fixed on the upstream of a PVC pipe. This is done to collect surface vibration measurements from the pipe and perform analysis on the vibrations using the signal analysis algorithm. The Esp8266 is equipped with Wi-Fi functionality servers our local server and a communication device for connecting to web-based data visualization application built using HTML, CSS and JavaScript. Fig 9 shows the circuit interfacing diagram for MPU6050 Arduinos and Esp8266 designe. Fig 10 shows the circuit schematics.

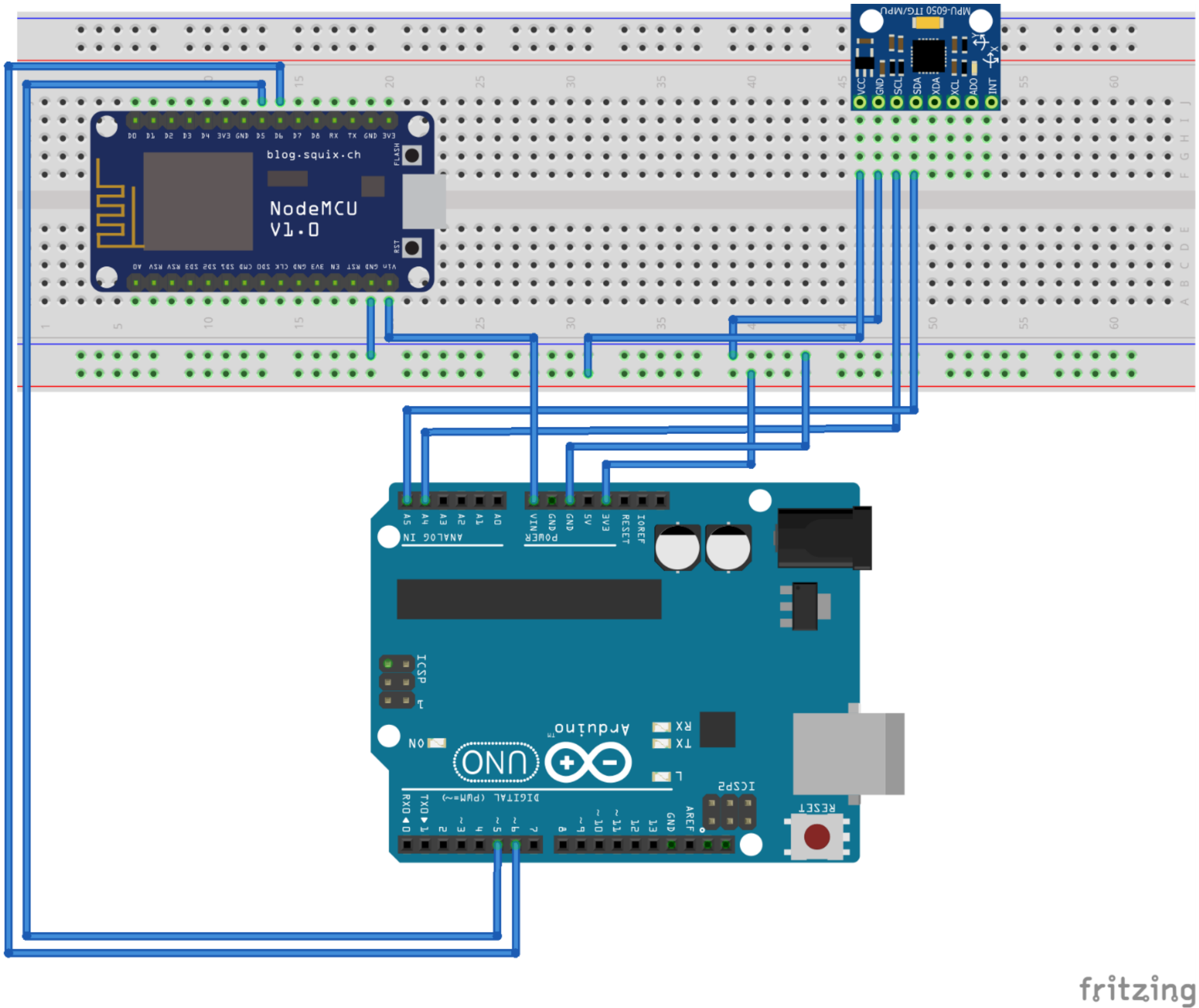


Figure 1. Interfacing of MPU6050 and Esp8266 and Arduino

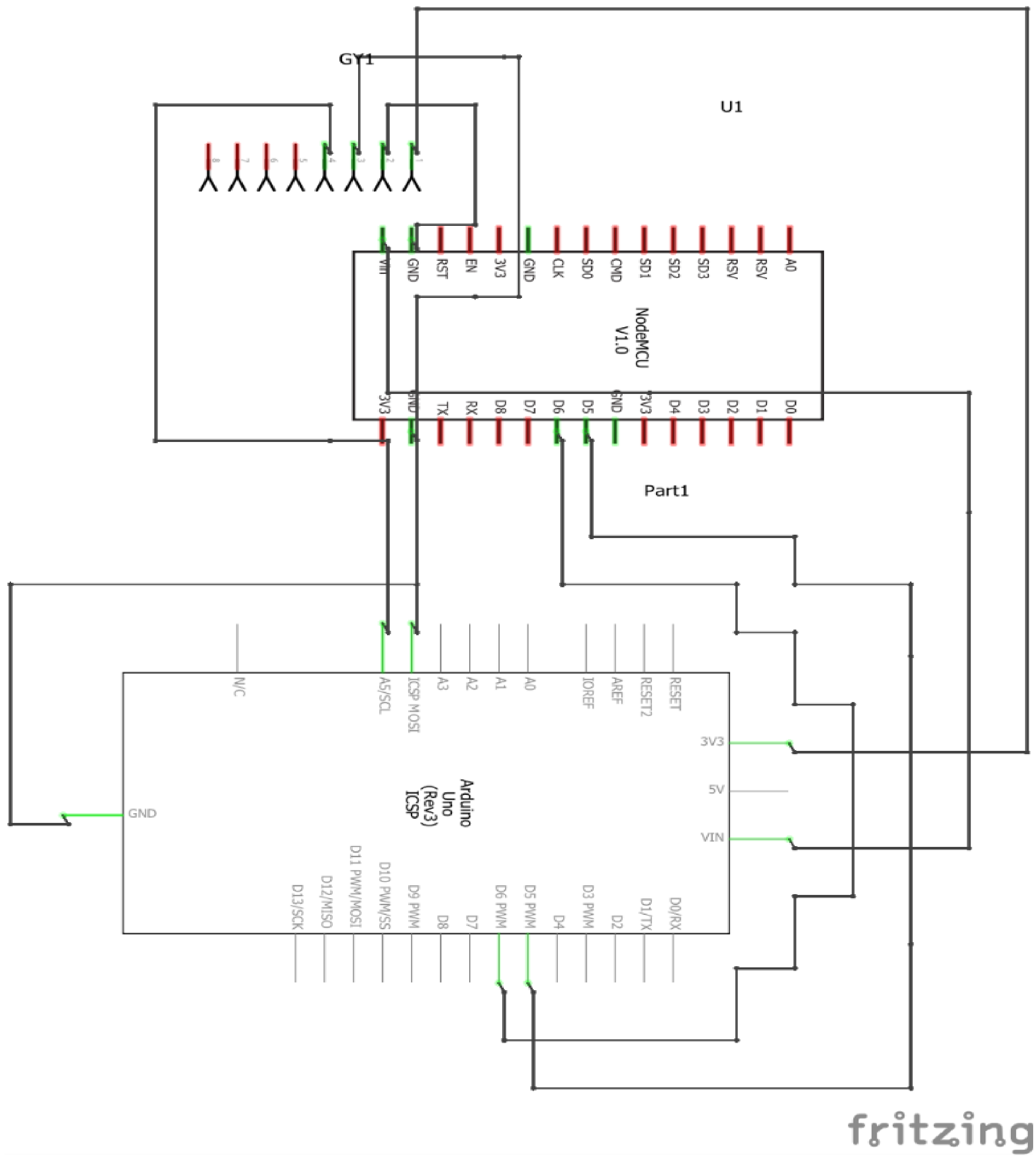
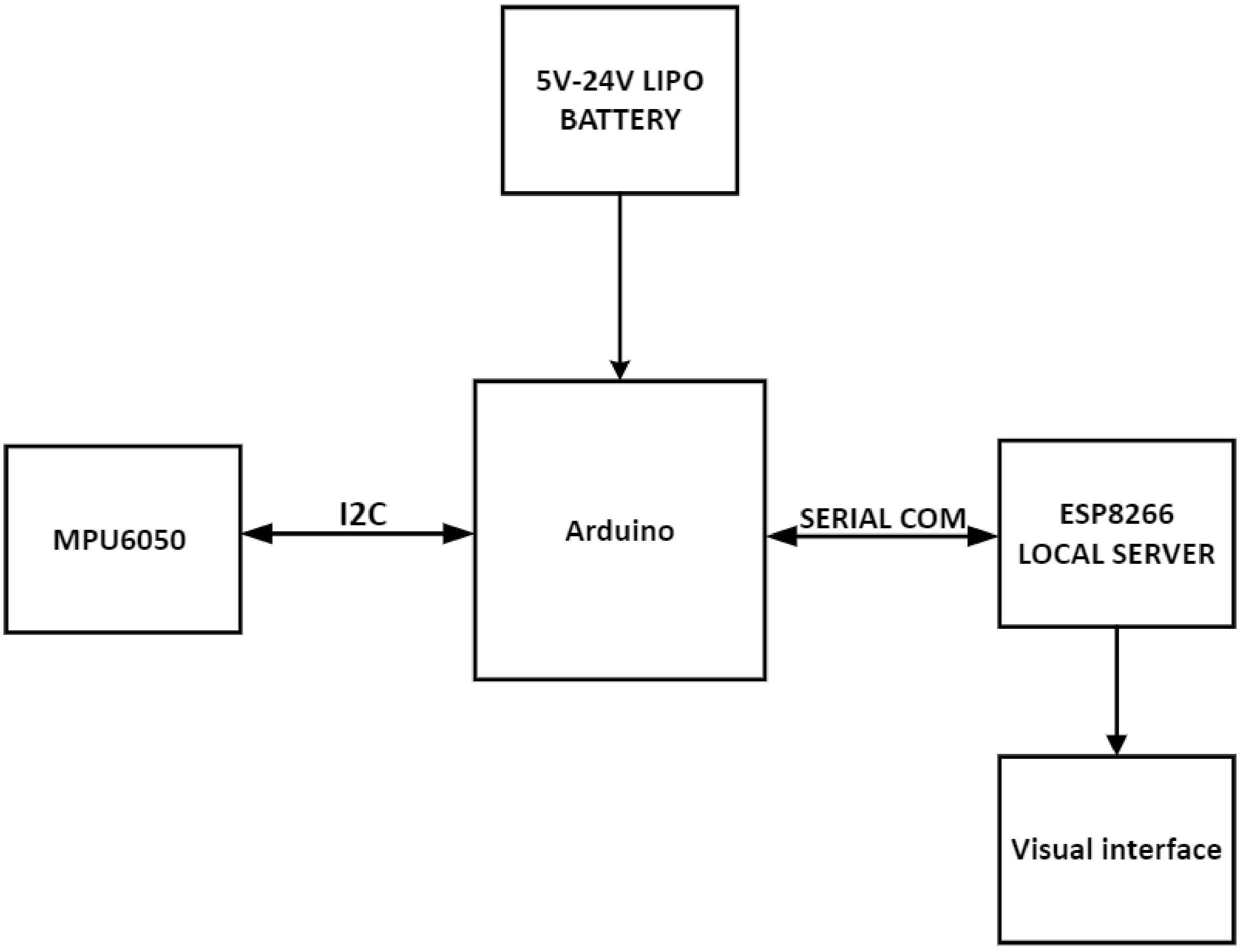


Figure 2. Schematic Diagram for Circuit.

2.5 Flow Control Diagram for System Design



2.7 Mathematical Models and Algorithm Analysis

2.7.1 Frequency Analysis

An ideal vibration time signal consists of two components: sine and cosine components. This component can be expressed with a complex number system of equation given by:

$$e^{-j\omega t} = \cos(wt) + i\sin(wt) \tag{1}$$

The above stated equation is the fundamental for Fourier computations. The frequency domain of a time signal can be computed mathematically using the Fourier expression:

$$X(k) = \sum_{n=0}^{N-1} x(n)\, e^{-j\left(\frac{2\pi}{N}\right)nk} \quad (k = 0,1 \ldots, N-1) \qquad (2)$$

N= FT sample size, x (n) = Time Domain Samples, X (k) = Frequency Domain samples

The Fast Fourier Transform algorithm which is based on the Discrete Fourier Transform is a popular computational algorithm used in the computation of the frequency domain resolution of a given time signal.

CHAPTER THREE

RESULTS AND ANALYIS

3.1 Overview

This chapter discusses the system implementation and test results obtained after testing our system prototype. Results and findings are also presented in this chapter.

3.2 System Operation

A prototype of the leak detection was built using a 50 cm PVC pipe mounted on two rubber gallons to offer support to the pipe. The system consists of four components: MPU6050 accelerometer sensor for recording surface acceleration of test pipe, an Arduino processing unit for processing surface acceleration readings, Esp8266 unit for routing processed data, and a web interface for reporting leak events. The system works by supplying water to the PVC inlet through a pipe hose from a water tap at full pressure. The accelerometer sensor is mounted on the pipe 30 cm from the inlet of the pipe. This was done to allow for sufficient surface vibration to occur before reaching the accelerometer sensor. The system was powered using a 9v battery but can support from 7V – 24V DC power source. Figure 10 shows the setup.

Figure 3. System Prototype setup

Prediction of leak occurrence is done using analysis of resolved frequency components of recorded surface acceleration of test pipe. This was achieved through the signal processing algorithm implemented on the processing unit. This algorithm is built based on Fourier Transforms. Surface acceleration readings of test pipes are passed as input arguments to the algorithm. The algorithm takes 64 data points from the recorded readings as x (n) defined in equation 2 (time domain samples). Using Euler's complex number notation defined in equation 1, the algorithm resolves the 64-time domain samples into a complex sine wave which represents the frequency components of the time signal. The algorithm then computes the complex dot products of the complex sine wave to produce the magnitude of the sinewave. The prediction threshold parameters for the occurrence of a leak test pipes are given in Table 2.

Tabular Data for Prediction Parameter Values

Leak		No leak	
frequency	amplitude	frequency	amplitude
X >125 Hz	X > 200	X < 125 Hz	X< 200

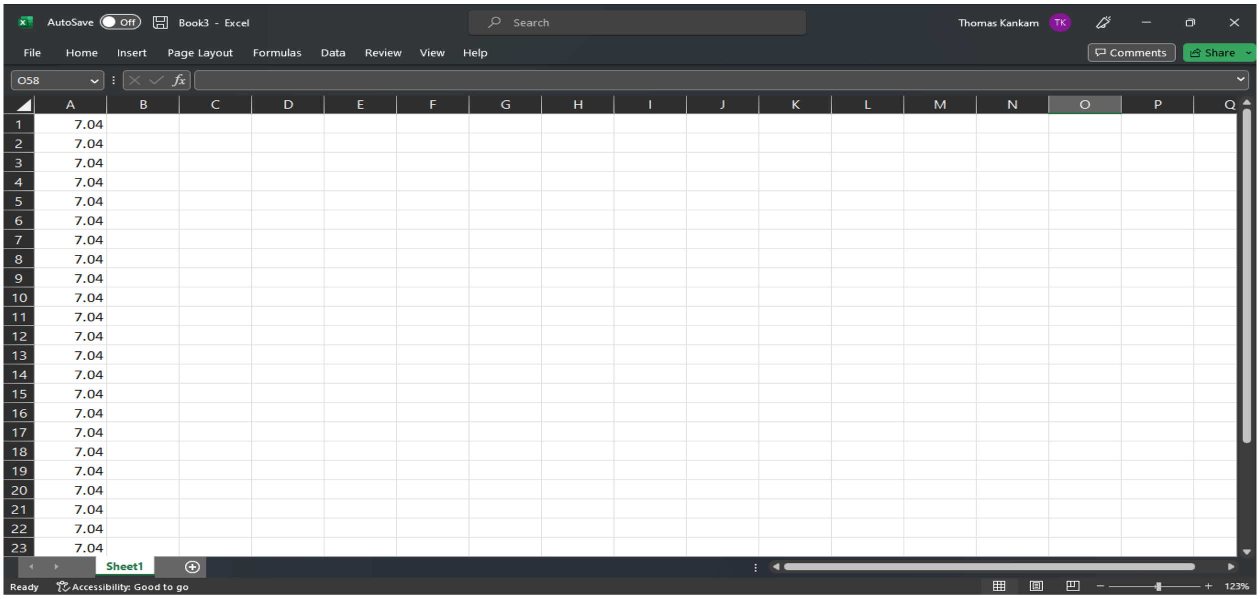
Table 3. Prediction parameter values.

3.3 Test and Results

3.3.1 Test Case 1

Figure 4. Test A

Readings recorded from pipe A which had no leakage spot was captured by the accelerometer sensor and transferred to the Arduino processing unit for the leak detection algorithm to be applied to the received data. The surface acceleration reading recorded by the mpu6050 sensor for pipe A is shown in Fig 13. Values are measured in m/s^2.



	A
1	7.04
2	7.04
3	7.04
4	7.04
5	7.04
6	7.04
7	7.04
8	7.04
9	7.04
10	7.04
11	7.04
12	7.04
13	7.04
14	7.04
15	7.04
16	7.04
17	7.04
18	7.04
19	7.04
20	7.04
21	7.04
22	7.04
23	7.04

Figure 5. Surface acceleration readings of test pipe A measured by mpu6050 sensor.

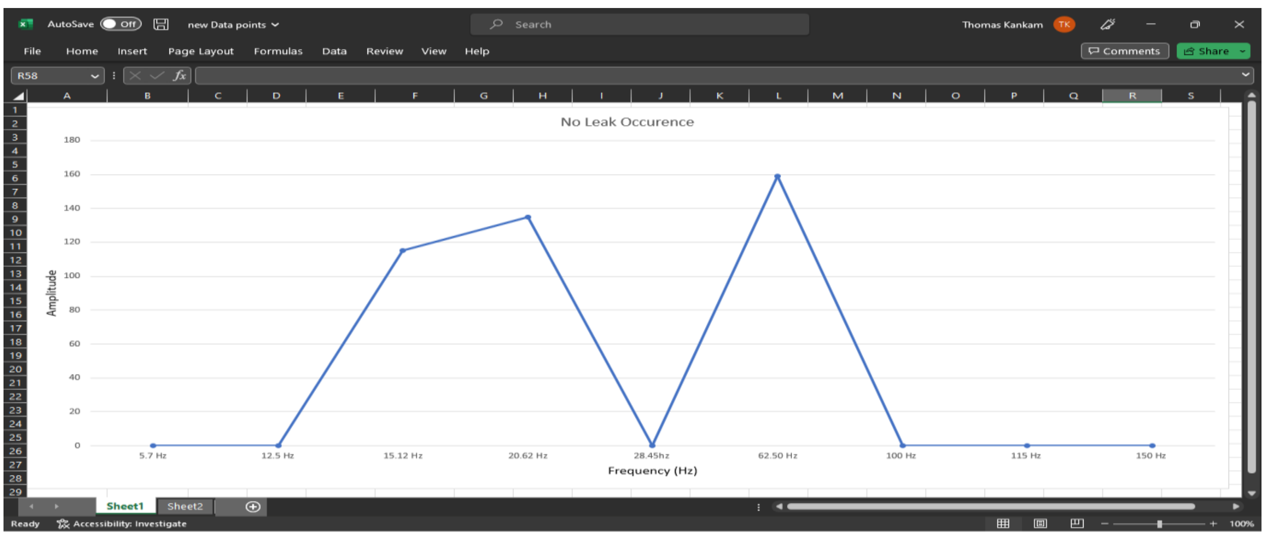


Figure 6. Amplitude against Frequency graph of collected and processed data for Pipe A

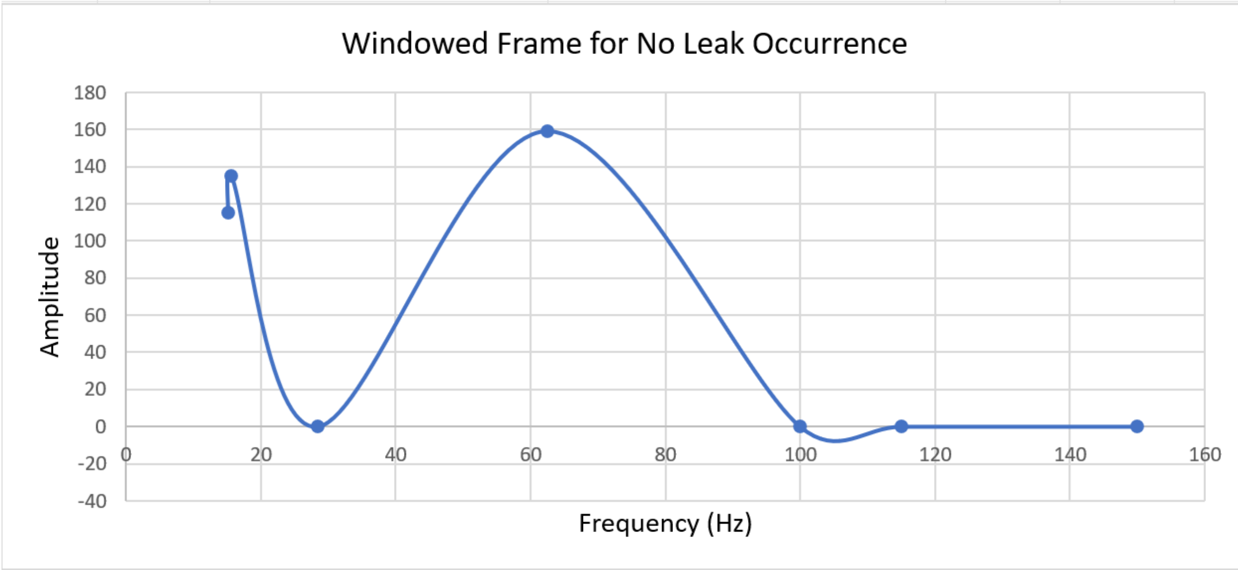


Figure 7. Windowed Frame for No Leak Occurrence

The processed data obtained from the algorithm is passed to our local server running our remote web server. The received data is visualized on the web-based monitoring system.

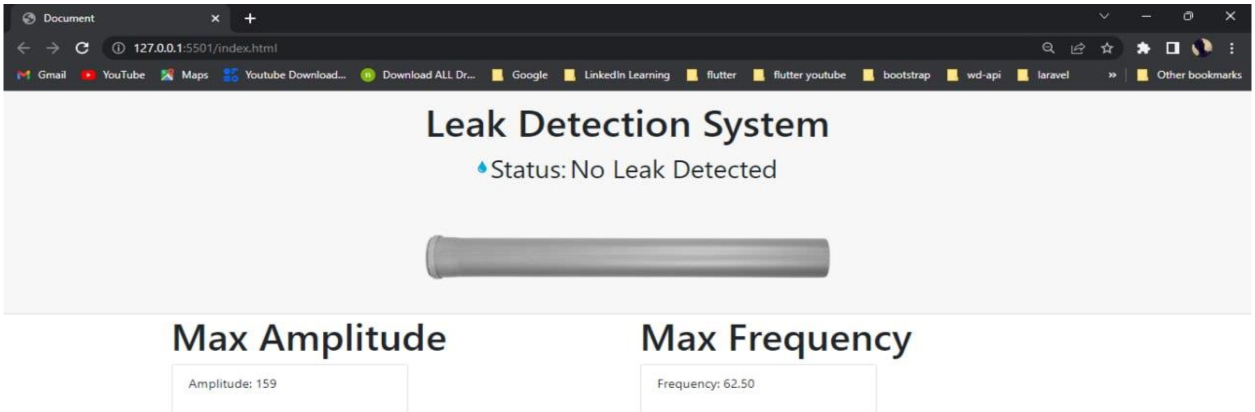
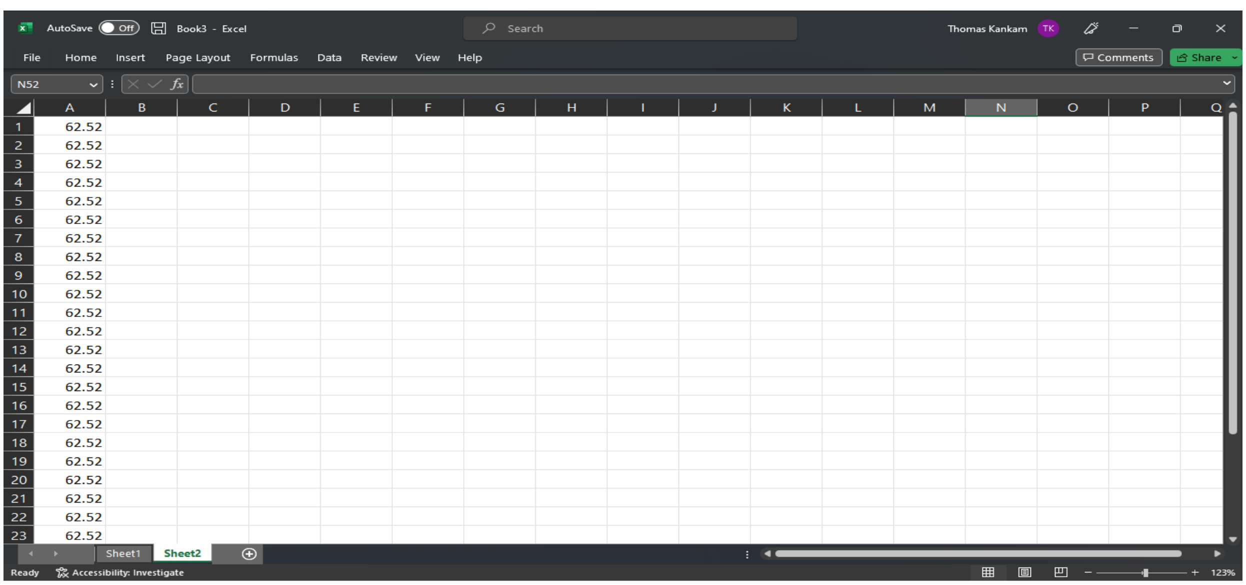


Figure 8. Web-based Leak status monitoring system results.

3.3.2 Test Case 2

Figure 9. Test B

Readings recorded from pipe B which had a leakage spot were captured by the accelerometer sensor and transferred to the Arduino processing unit for the leak detection algorithm to be applied. The surface acceleration reading recorded by the mpu6050 sensor for pipe B is shown in Fig 13. Values are measured in m/s^2.



	A
1	62.52
2	62.52
3	62.52
4	62.52
5	62.52
6	62.52
7	62.52
8	62.52
9	62.52
10	62.52
11	62.52
12	62.52
13	62.52
14	62.52
15	62.52
16	62.52
17	62.52
18	62.52
19	62.52
20	62.52
21	62.52
22	62.52
23	62.52

Figure 10. Surface acceleration readings of test pipe B measured by mpu6050 sensor.

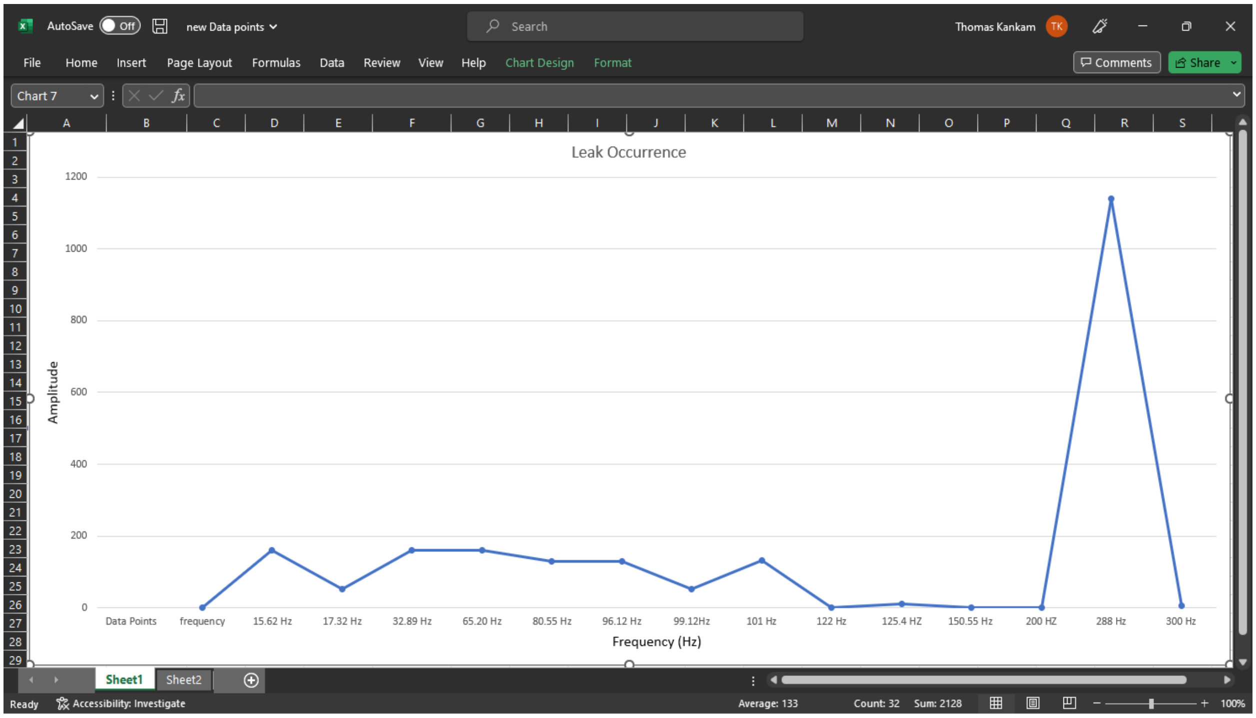


Figure 11. Amplitude against Frequency graph of collected and processed data for Pipe B

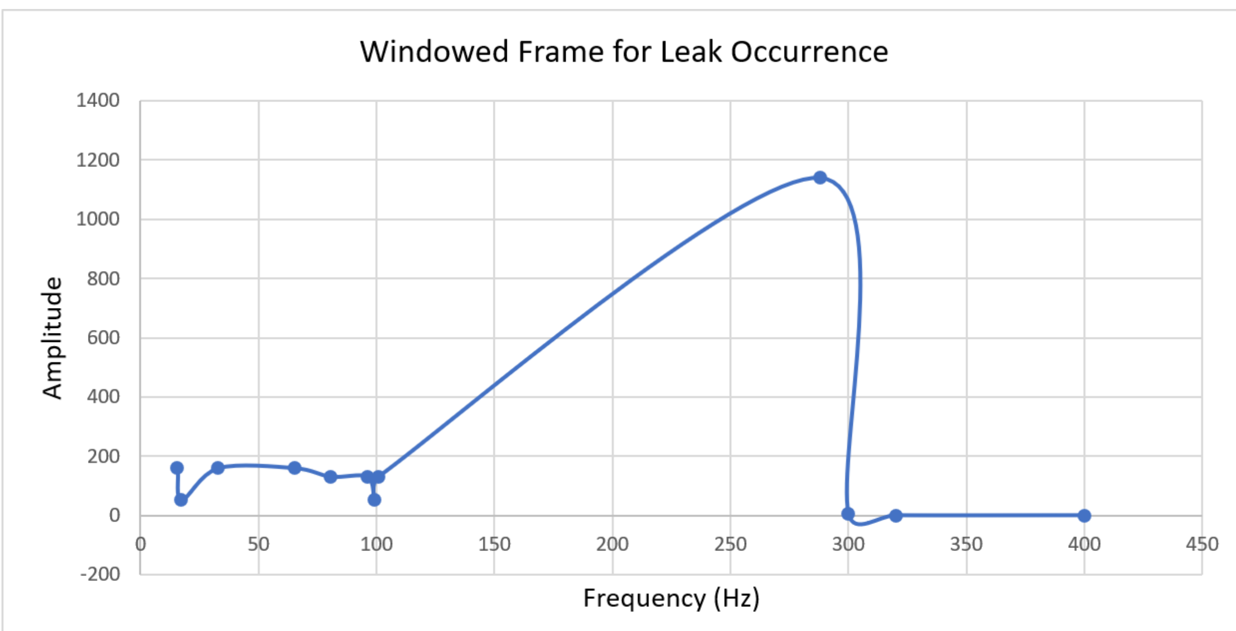


Figure 12. Windowed Frame for Leak Occurrence

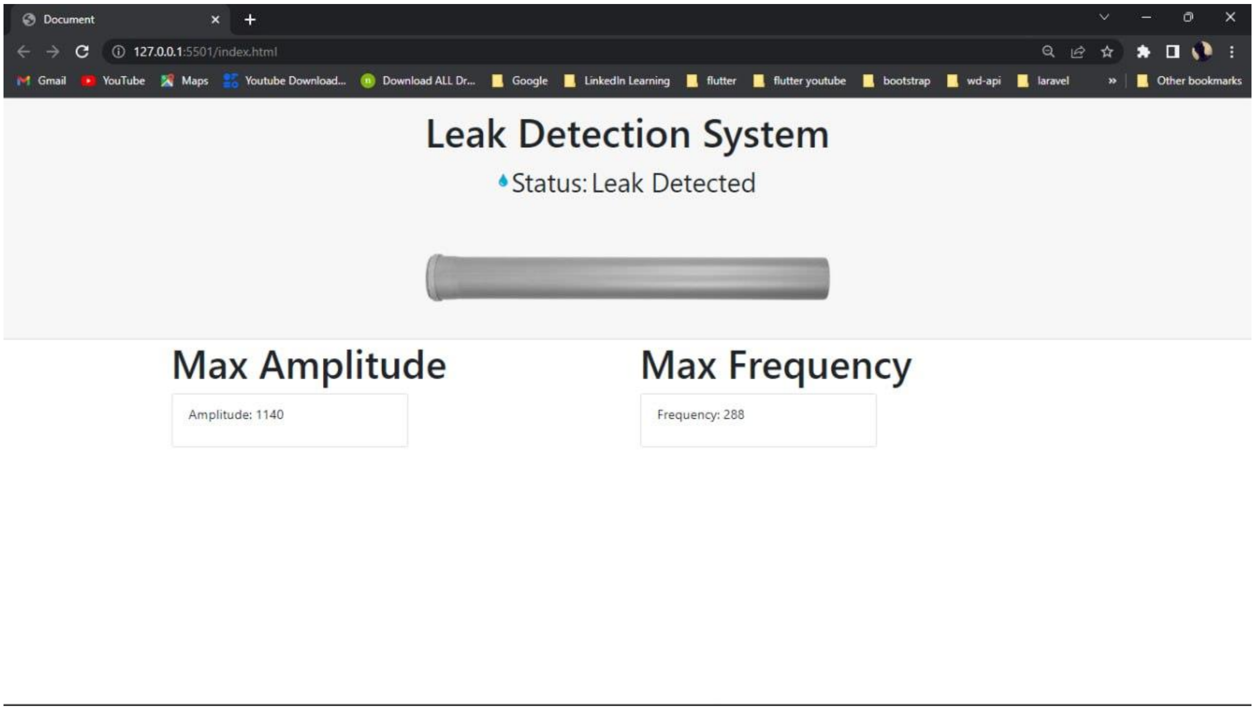


Figure 13. Web-based Leak status monitoring system results.

3.4 Analysis And Conclusion

The practical prototype tests were conducted to simulate the system as close to real-life scenarios as possible. Several scenarios of testing were done to prove the effectiveness of the prototype. The scenarios created for the experiments were designed to reflect the real-world experience.

The first test case analyses leak detection response by creating normal conditions without leaks. Leakage was recorded automatically in terms of frequency and amplitude. The leakage process time was recorded in the software, so that sensor data could be compared to it. The first test was done without a leak, which produced a maximum amplitude and frequency result of 62.5Hz and 159. The recorded values if compared to the threshold value fall below it hence indicating the presence of no leak.

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Link to project source code: yankeygilbert/Leak-Detection-in-Pipelines-Using-Vibration-Analysis-: This is a project aimed at achieving leak detection in Pipelines through pipes surface vibration analysis. (github.com)