Automatic Forklift Prototype using Vibrational Analysis

PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

This is to certify that the thesis entitled **Automatic Forklift Prototype using Vibrational Analysis** submitted by **Varshitha Thilak Kumar (Register Number - CB.SC.U4AIE23258)**, **Siri Sanjana S (Register Number - CB.SC.U4AIE23249)**, **Shreya Arun (Register Number - CB.SC.U4AIE23253)**, and **Anagha Menon (Register Number - CB.SC.U4AIE23212)** for the award of the **Degree of Bachelor of Technology** in **COMPUTER SCIENCE ENGINEERING - ARTIFICIAL INTELLIGENCE** is a bonafide record of the work carried out by them under my guidance and supervision at Amrita School of Artificial Intelligence, Coimbatore.

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DECLARATION

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To the best of our knowledge, this work has not formed the basis for the award of any degree, diploma, associateship, fellowship, or any other similar award to any candidate in any university.

Place:Coibatore **Signature of the Students**

Date:21.04.2025

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List of Abbreviations

FFT	Fast Fourier Transform
WT	Wavelet Transform
STFT	Short-Time Fourier Transform
MPU6050	Microprocessor Unit 6050
RPM	Revolutions Per Minute

Abstract

This project presents the design and development of an automated forklift prototype that uses vibrational analysis to determine load conditions and potential defects. Using vibration sensor data, we analyse the mechanical stability and operational health of the lifting mechanism. A Raspberry Pi-based control system that manages sensor inputs enables real-time monitoring. This prototype aims to increase automation and security in warehouse environments.

Chapter 1

Introduction

Material handling systems are changing from brute-force instruments to intelligent partners as a result of the quick integration of robotics and embedded technologies into industrial equipment. Among these, the common forklift, which is used extensively in logistics and warehouses, is still mainly ignorant of its own mechanical state. Despite improvements in mobility and weight capacity, conventional forklifts are unable to continuously assess the structural integrity of their machines, particularly when performing crucial tasks like lifting. This blind gap puts both production and safety at risk by causing hazardous situations like overload, mechanical wear and tear, or unexpected failure.

In order to identify early indicators of mechanical stress and structural irregularities during lifting operations, this project highlights the creation of a smart forklift prototype that integrates embedded sensors, real-time monitoring, and vibration analysis. The forklift continuously assesses its lifting dynamics by combining vibration sensors with a Raspberry Pi-based control system, providing timely alarms and predictive insights. Realistic visualisation, control, and analysis of mechanical behaviours under load are made possible by the prototype's operation within a simulated 3D warehouse environment created with Pygame and OpenGL.

The system records and analyses vibration data, exporting it for time-domain and frequency-domain analysis through signal processing techniques, in addition to visualising forklift operations and load interactions. By bridging the gap between conventional lifting systems and intelligent, self-aware machines, this hardware and software combination seeks to improve operational safety, prolong the life of equipment, and open the door to more intelligent industrial automation.

Table 1.1: Literature Review Summary

Paper Title	**Authors**	**Year**	**Key Contributions**
Vibration Research on Fork-Lift Truck by Harmonic Analysis	Ming Liang Yang et al.	2005	Analyzed forklift vibrations using harmonic analysis to improve operator comfort and system stability.
JB/T3300-1992 Counterbalanced Forklift Whole Machine Test Methods	National Standards	1992	Provided standardized vibration and performance testing methods for forklift validation.
Vibration Analysis of Motorcycle Frame	Huang Zehao et al.	2016	Investigated frame vibration characteristics; methodology applicable to forklift frame integrity analysis.
A Review on Vibration-Based Condition Monitoring of Rotating Machinery	Monica Tiboni et al.	2022	Comprehensive review on sensor placement, signal acquisition, and predictive maintenance techniques.
A Review of Vibration Analysis and Its Applications	Thuy Chu a , Tan Nguyen,Hyunsang Yoo a ,Jihoon Wang	2024	Summarized vibration analysis applications across industries for fault detection and reliability improvement.
A Review of Vibration Analysis Techniques for Rotating Machines	Saurabh Singh,Dr. Manish Vishwakarma	2021	Compared frequency-domain and time-frequency-domain methods for machine condition monitoring.

1.1 Problem Statement

Due to their inability to monitor structural health in real time, conventional forklifts are unable to identify mechanical stress or lifting mechanism flaws while in use. Because of this, problems such as structural fatigue or component failure sometimes go overlooked until major damage happens, which presents major safety risks and results in unscheduled downtime. An intelligent embedded system that can use vibration analysis to continuously monitor the forklift's lifting action is required to address this. The suggested solution seeks to improve safety, dependability, and operational efficiency in warehouse settings by utilising sensors and a Raspberry Pi-based processing unit to identify early indications of failure or unusual load situations.

1.2 Objectives

- to create a smart forklift prototype that is affordable and has vibration sensors for in-the-moment lifting mechanism monitoring.
- to gather and analyse vibrational data from the lifting assembly of the forklift in order to evaluate load conditions and identify mechanical faults early.
- to improve operational safety and stability by facilitating early fault identification and promptly issuing notifications during abnormal load handling.
- to integrate advanced sensing and analytical capabilities in order to support automation and predictive maintenance in industrial and warehouse settings through PyGame Simulation with OpenGL and Scipy

1.3 Organization of the Report

The structure of this report is outlined below:

- **Chapter 1: Introduction**
  summarises the project's objectives, the problem definition, and the pertinent literature review. It gives background on forklift monitoring, industrial automation, and the importance of real-time vibration measurement for maintenance and safety.

- **Chapter 2: Background**
  explains the main components and technology, with an emphasis on the Raspberry Pi, load cell, and FFT signal processing technique. The fundamentals of sensor integration for real-time data collection and analysis are also covered in this chapter.

- **Chapter 3: System Architecture and Methodology**
  explains the vibrational signal analysis pipeline, data collection methodology, and lifting procedure. This covers the hardware design, the Load Cell sensor position, and the stress simulation technique used to test the forklift under various load scenarios. The emphasis is on identifying possible mechanical problems through vibration analysis utilising FFT.

- **Chapter 4: Experimental Setup and Results**
  explains the load cell installation process, testing protocols, and failure simulation setup. In order to detect anomalies in the lifting mechanism, it displays the vibrational analysis findings using FFT in addition to the real-time monitoring performance.

- **Chapter 5: Conclusion and Future Scope**
  summarises the project's major achievements, evaluates the precision of the system that was created, and lists potential enhancements, such as the inclusion of wireless notifications and the incorporation of machine learning for predictive maintenance. It also offers recommendations for upcoming projects aimed at improving the system's functionality.

Chapter 2

Background

2.1 Introduction

Forklifts are now essential to industrial automation and warehouse logistics, but it's still difficult to keep an eye on their condition and performance in real time. Conventional maintenance methods frequently depend on recurring inspections, which are unable to identify early mechanical problems or risky usage habits. This emphasises the necessity of intelligent systems that can continuously assess the performance and operational health of the forklift.

The main goal of our solution is to provide a forklift prototype the capacity to recognise and examine vibratory patterns produced when it is in use. The system uses a Raspberry Pi, a Load Cell sensor, and FFT signal processing techniques to detect anomalies like imbalance, overloading, or wear and tear in mechanical parts.

Giving the forklift a "sense of feel" for its operating status is the main goal. This makes it possible to identify any mechanical faults early on, enabling the system to take proactive measures before problems worsen and become major defects. Our prototype can recognise and learn from its movements and operating environment because it is built to not only navigate but also "sense" its condition through real-time data analysis.

Chapter 3

Proposed Work

3.1 Overview

The goal of the suggested system is to create a smart forklift prototype that has a load cell positioned strategically to track vibrations brought on by different loads. Sensing, which records vibrational data in real time; Signal Processing, which uses methods like FFT (Fast Fourier Transform) to extract meaningful patterns; Anomaly Detection, which detects anomalies like overloading or mechanical wear; and Control Response, which initiates alerts or preventive measures to guarantee safe forklift operation, are the four main modules of the system. The objective is to make it possible to detect load-related problems in real time, turning the forklift into a clever, responsive system that improves warehouse operations' safety and dependability.

3.1.1 System Architecture and Mechanical Design

The system is built on a combination of **mechanical actuation**, **real-time processing**, and **smart sensing**, all coordinated by a **central controller** (Raspberry Pi 4). The key components include the **lifting mechanism**, **locomotion system**, **load analysis setup**, and **remote interface integration**.

Fork Lifting Mechanism – Lead Screw and Stepper Motor

The fork is lifted utilising a lead screw mechanism connected to a NEMA series stepper motor. The stepper motor's rotation creates linear displacement of the lead screw, allowing the fork to move precisely up and down.

This design provides precise control over fork position and minimises backlash, ensuring safe load handling. The Raspberry Pi sends step and direction signals to the stepper motor driver, which drives the motor.

This design offers minimal backlash and accurate control over the fork position, which is essential for safe load handling. The motor is driven by a stepper motor driver that accepts step and direction signals from the Raspberry Pi.

Raspberry Pi-Based Motor Control

The Raspberry Pi 4 acts as the master controller, programmed to manage both the stepper motor driver and the Mecanum wheel motors.

- It generates step pulses to control the position and speed of the lifting motor.
- It also processes sensor data in real-time, enabling smart decisions based on load conditions or detected anomalies.
- Motor control logic includes microstepping to ensure smooth motion and precision.

Locomotion – Mecanum Wheel Drive

The system is mobile and equipped with four Mecanum wheels, giving it holonomic movement capabilities.

The Raspberry Pi independently controls the motors of each wheel, allowing the forklift to move forward, backward, strafe sideways, and rotate in place.

This setup is ideal for maneuvering in tight or complex spaces like warehouse aisles. Direction and velocity control are implemented through PWM signals to motor drivers.

Sensor Integration – Load Cell

In order to measure weight and track load-induced vibrations in real time, a load cell is installed directly on the fork. If necessary, an Analog-to-Digital Converter (ADC) is used to obtain the load cell data.. Analysis of fork stability, imbalance, or hazardous loading conditions is aided by the combination of weight and vibration data.

App and Remote Interface Integration

To enhance usability and control, the system is connected to a custom-built Android application that allows:

- Manual control of the lifting and locomotion mechanisms
- Live monitoring of sensor values (tilt, weight, vibrations)

Communication is established via **Bluetooth or Wi-Fi**, making the prototype fully wireless and remotely operable.

To improve remote control and monitoring, a mobile app was integrated into the system interface. The app was developed using the Flutter framework for cross-platform portability and responsive UI design.

The development environment was Android Studio, and the programming was done in Dart, Flutter's native language. The application has clearly labelled interactive buttons for controlling the following operations:

- Forklift movement directions (forward, backward, left, right, and rotate)
- Forklift lift and drop controls
- Displaying sensor feedback, such as tilt angle or load weight (if incorporated)

Flutter's widget system was used to create an easy-to-use front-end interface with fluid user interaction. The app's back-end logic facilitates communication between the user interface and the system's control hardware, specifically the Raspberry Pi. Button presses trigger backend functions that send specific commands over Bluetooth or Wi-Fi, depending on the communication mode.

During first testing on a laptop, the program returned correct results. For instance, hitting the **”Left”** button results in the following response: *”You have pressed left”*.

This checks the app's readiness for real-time control deployment by ensuring adequate connectivity between UI and backend logic.]

3.1.2 Mobile App Development and Integration

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3.2 Sensing

The core sensing mechanism relies on a:

- **Load Cell:**placed underneath the prototype's fork to record vibratory variations and weight distribution while the forklift lifts and transports objects.

- **Raspberry Pi 4:** Serves as the brain of the operation, acquiring analog data (through an ADC if required) and processing it further. It also communicates with a remote interface for monitoring.

High sensitivity to variations in load dynamics is ensured by this configuration, allowing for thorough tracking of forces and disturbances while in operation.

3.3 Signal Processing

Once the load cell data is acquired, the system uses advanced signal processing to understand the forklift's condition:

- **Fast Fourier Transform (FFT):** Converts time-domain load vibrations into frequency-domain data to identify patterns and spikes that may suggest mechanical issues.

3.4 Control Response

Upon identifying an anomaly, the system can:

- Activate visual or audible alerts

- Send notifications to a connected Android phone or dashboard interface

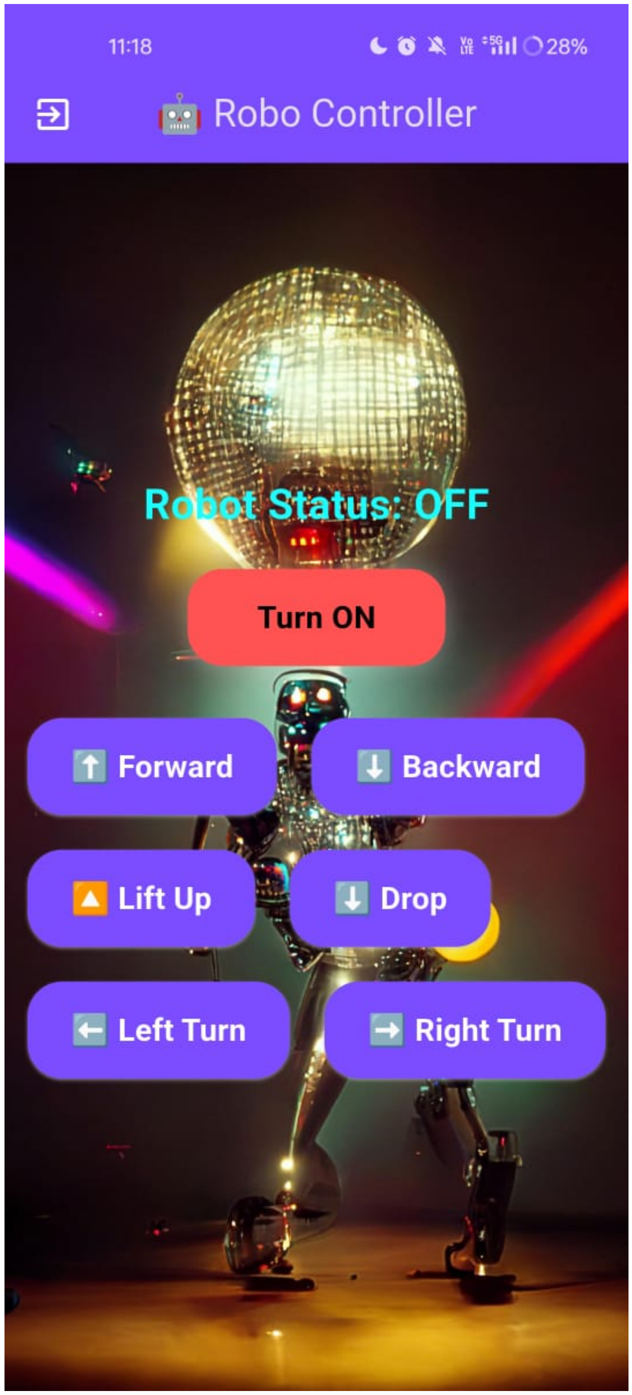

Figure 3.1: Screenshot of the Flutter-Based Mobile App Interface

- Either reduce the speed of the Forklift or stop lowering the fork of the forklift.

3.5 Simulation

A structured simulation setup was created in order to assess the forklift's capacity to identify mechanical stress and abnormalities during lifting operations. The prototype was made to mimic actual warehouse operations, such as moving and picking up bricks of different weights. The goal of this dynamic simulation is to accurately depict the mechanical strain and load variations seen in industrial material handling. To identify vibrations and force variations brought on by different load weights, the system makes use of a load cell that is positioned thoughtfully at the lifting fork's base. As the forklift engages in actions like lifting and carrying blocks, the load cell captures voltage signals representing mechanical activity. The Raspberry Pi 4 serves as the system's central processing unit and samples these signals in real time. The gathered signals are first examined in the time domain, where variations in amplitude indicate the strength of vibration during the lifting, carrying, and positioning stages of motion. The Fast Fourier Transform (FFT) method is then used to convert these time-based signals into the frequency domain. The prominent frequency components linked to aberrant mechanical vibrations or excessive load-induced stress can be identified thanks to this transformation. The physical configuration and mobility of the forklift are meticulously modelled in the simulation, taking into account the proportions and mechanics of the real world. A firm foundation for all operations is provided by the forklift's chassis, also known as the base, which has dimensions of 1.5 units for width, 2.5 units for length, and 0.5 units for height. This chassis serves as the forklift's central component in the simulation, and other parts like the wheels and lifting mechanism are installed on it. With 20 units on each side, the warehouse space is roomy enough to accommodate numerous racks, shelves, and crates for practical task execution and navigation. The use of mecanum wheels, which are crucial for omnidirectional mobility, is a notable aspect of the simulation. The radius and width of each wheel's construction are 0.3 and 0.2 units, respectively. Four mecanum wheels, each with twelve rollers angled at a 45-degree angle, are positioned at the chassis' corners by the code. The forklift can travel not only forward and backward but also sideways and diagonally thanks to this configuration, which closely resembles the special characteristics of actual mechanum-wheeled vehicles. Small cylinders attached at the proper angles around the circle of each wheel serve as the visual representation of the rollers, which are drawn using OpenGL primitives. With a fork that is 1.0 units wide, 1.8 units long, and 0.1 units thick, the lifting mechanism is equally intricate. Smooth vertical movement is made possible by the fork's mounting on two parallel threaded rods, each of which has a radius of 0.05

units and a length of 2.0 units. The stepper motors (0.25 units in size) are connected to the threaded rods by couplers, which are shaped like short cylinders and convey rotating motion for lifting. To improve visual authenticity, the fork platform is depicted as a translucent acrylic slab, and the simulation also has a load cell on the fork for weight measurement. Together, these mechanical specifics and dimensional decisions guarantee that the simulated forklift closely mimics the size and characteristics of its real-world equivalent, offering a strong platform for vibration/load study and visualisation.

The code integrates physical dynamics with sensor-based data collecting for vibration

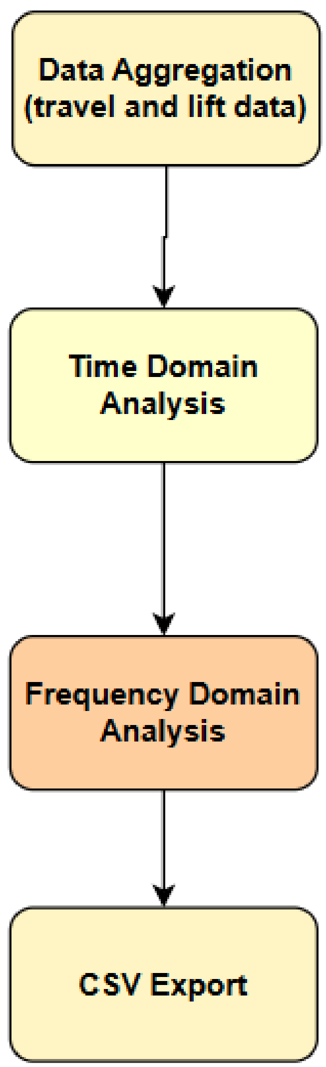

Figure 3.2: Data collected from the simulation

and load analysis to mimic a forklift operating in a warehouse setting. With the help of OpenGL and Pygame, the simulation is produced, producing a 3D dynamic scenario in which the forklift is able to move, pick up, and position bricks on shelves. The forklift's movement, lifting, and block manipulation are controlled via keyboard inputs, with real-time updates to the forklift's position, fork height, and rotation. For realism, the simulation environment has shelves, crates, and warehouse limits, and geometric primitives are used to depict important mechanical parts including wheels, forks, and threaded rods. The primary function is the real-time gathering and examination of loadcell and vibration data while the forklift is in operation. The influence of mechanical oscillations and load variations is simulated by creating and recording vibration amplitudes when the forklift moves or raises a load. This information is saved and then used for analysis; for example, the code initiates a vibration analysis procedure when a block is positioned. This procedure computes the frequency spectrum using the Fast Fourier Transform (FFT), creates a plot of vibration amplitude vs time, and records the time-series vibration data to a CSV file. With the use of these plots, dominant vibration frequencies may be found and system stability can be evaluated across various operating stages. The algorithm also offers a thorough summary and visualisation of operating states, including frequency-domain features, load transitions, and vibration intensities. The simulation calculates statistics like the average and maximum vibration for each condition and records and shows empty, medium, and heavy load periods. By combining these elements, the simulation replicates the type of sensor data analysis that would be carried out in actual industrial monitoring systems in addition to showing the forklift's physical behaviour under various weights. This method supports predictive maintenance and safety analysis in automated warehouse environments by allowing users to see how operational events affect vibration and load.

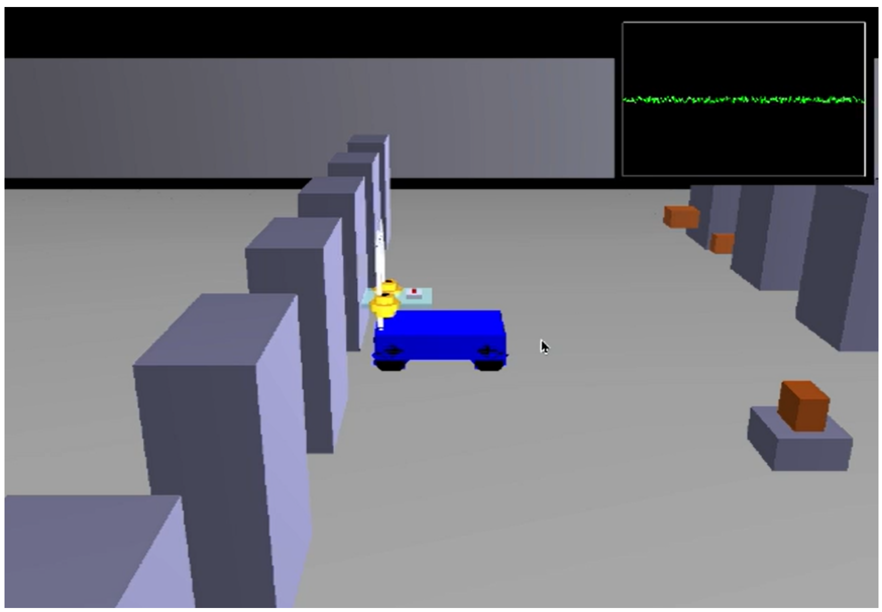

Figure 3.3: Forklift with loadcell on fork for vibrational analysis positioned in a warehouse

Chapter 4

Results and Discussion

4.1 Motion and Lifting Mechanism Design

4.1.1 Mecanum Wheel-Based Locomotion

The forklift prototype is equipped with four Mecanum wheels, which provide omnidirectional movement capabilities. Each wheel contains a set of rollers oriented at 45 degrees, allowing the vehicle to move forward, backward, sideways, and even diagonally without changing its orientation.

- **Mobility Advantage:** The omnidirectional control enabled by Mecanum wheels is ideal for confined warehouse environments, where space constraints demand high maneuverability.
- **Control Strategy:** The direction and speed of each wheel are controlled independently using a Raspberry Pi, which sends PWM signals to the motor drivers controlling the DC motors.

4.1.2 Lifting Mechanism with Lead Screw and NEMA Stepper Motor

A NEMA 17 stepper motor and a lead screw are used in the forklift's lifting mechanism. The fork may move precisely vertically thanks to this component.

- **Lead Screw Function:** The forklift platform is raised or lowered by the stepper motor's rotation of the lead screw, which transforms rotary motion into linear motion.

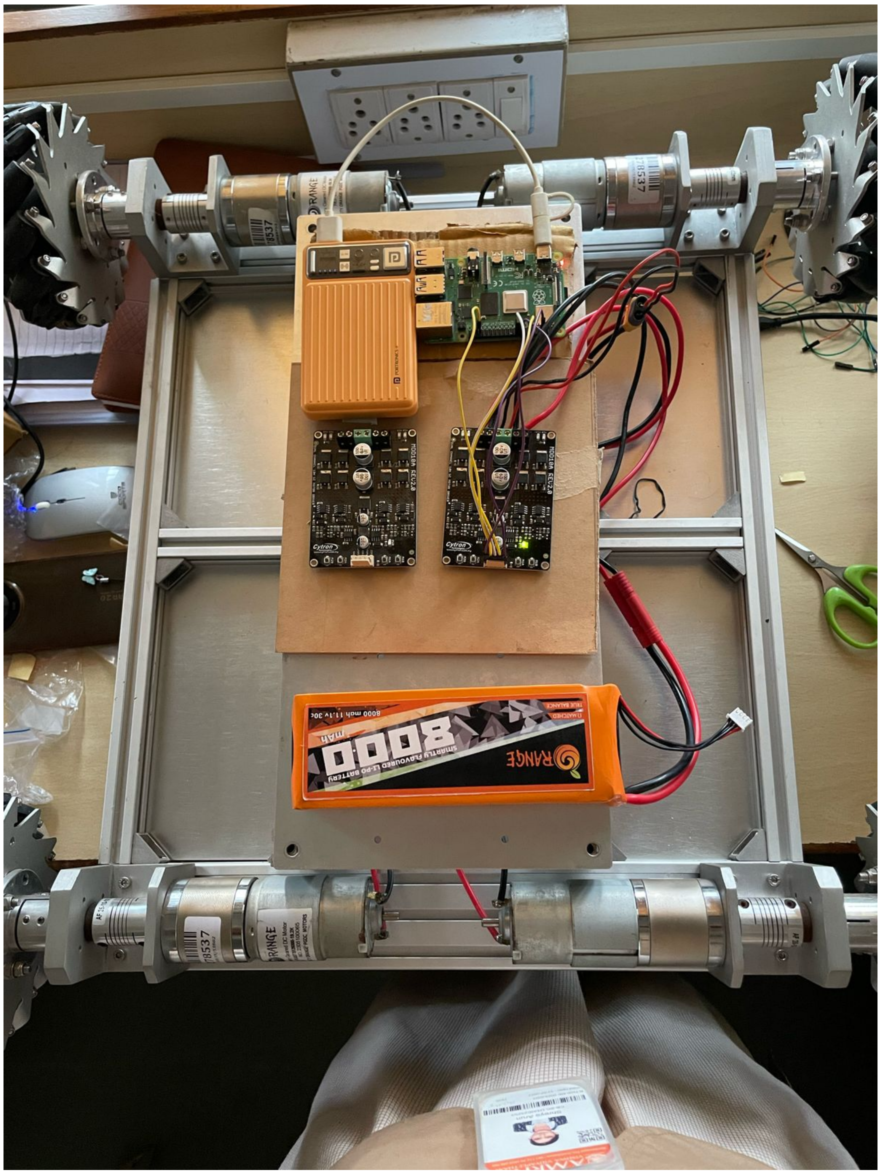

Figure 4.1: Mecanum wheel configuration and movement vectors

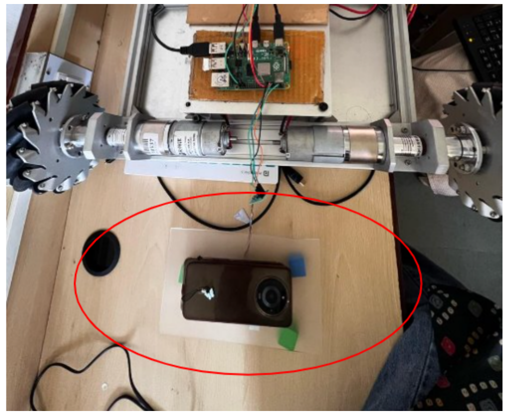

Figure 4.2: Dataset collected from load cell in the hardware model

load_cell_data

Timestamp (s)	Weight (g)
0.3269	134.72
0.7660	134.56
1.2036	134.70
1.6416	134.78
1.9887	134.68
2.4264	134.58
2.8655	134.64
3.2942	134.80
3.6514	134.66
4.3930	134.52
4.8214	134.71
5.2595	134.62
5.7894	134.62
6.3088	134.65
6.6556	134.55
7.0939	134.55
7.5318	134.67
7.9707	134.55

Figure 4.3: Dataset collected from load cell in the hardware model

- **Precision:** In order to raise or lower the forklift platform, the stepper motor turns the lead screw, transforming rotary action into linear motion.
- **Load Handling:** The system can lift moderate loads with good stability thanks to the lead screw's mechanical advantage.

4.1.3 Raspberry Pi-Based Control Integration

The main controller for the lifting and moving mechanisms is a Raspberry Pi.

- **Motor Drivers:** The NEMA stepper motor is controlled by the Raspberry Pi through an interface with stepper motor drivers (such as the A4988 or DRV8825).
- **Input Control:** A graphical user interface (GUI) or wireless control interface (like Bluetooth or Wi-Fi) is used to receive commands.
- **Synchronization:** Moving and lifting at the same time are examples of coordinated operations made possible by the Pi's synchronised control of the lifting mechanism and wheel motion.

4.1.4 Role of Motion and Lifting System in Prototype Performance

Mecanum wheels and an accurate lifting mechanism improve the forklift prototype's overall performance:

- **Navigation Efficiency:** Navigating through tight spaces and around sharp corners is made easier with omnidirectional motion.
- **Lifting Accuracy:** For load cell measurements and vibrational analysis, the lead screw mechanism guarantees steady and regulated lifting operations.
- **Integrated Control:** Compact design, low power consumption, and centralised control are guaranteed by a Raspberry Pi single-board computer.

This integrated system offers a scalable and affordable way to automate material handling duties in small warehouses.

As seen in the third composite plot, the analysis of hardware data combines vibration intensity, frequency analysis, and load cell readings to give a thorough picture of forklift operation. Empty, medium, and heavy load states are distinguished readily by the top panel,

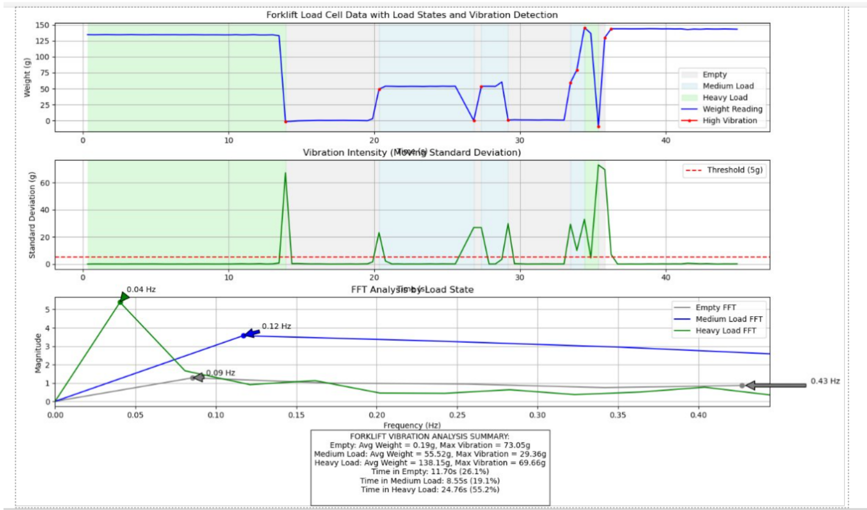

Figure 4.4: Analysis of Dataset collected from load cell in the hardware model

which tracks the weight measurements over time. As seen in the middle panel, where the vibration standard deviation acts as a gauge of dynamic activity, the shifts in vibration intensity indicate the transitions between different phases. Significantly, high vibration intervals coincide with load changes or periods of high operation, above the predetermined threshold and indicating possible danger areas. The bottom panel presents an FFT-based comparison of vibration across different load states, revealing that the dominant vibration frequencies and their magnitudes vary depending on the load. For instance, the heavy load state exhibits higher magnitude vibrations at specific frequencies, which can be attributed to increased mechanical stress and altered dynamic characteristics. The summary statistics further quantify these observations, detailing the average and maximum vibration levels for each load condition, as well as the proportion of time spent in each state. This data-driven approach enables precise identification of operational patterns that may contribute to wear or failure. The hardware analysis gives operators and maintenance staff useful insights by combining load, vibration, and frequency data. Specific interventions, like modifying handling protocols or planning preventive maintenance during high-risk times, are made easier by the ability to link high vibration events to particular load states and operational transitions. In the end, this comprehensive monitoring system supports data-driven decision-making for asset management and operational excellence while improving the dependability and safety of forklift operations. A picture of the system's dynamic response during travelling and lifting operations is given, which simulates forklift vibration over time. When mechanical systems are subjected to repeating forces, oscillatory motion is present, as evidenced by the periodic fluctuations in the vibration amplitude. With a noticeable disruption or spike around the halfway mark, which could be the result of a brief incident like an abrupt load

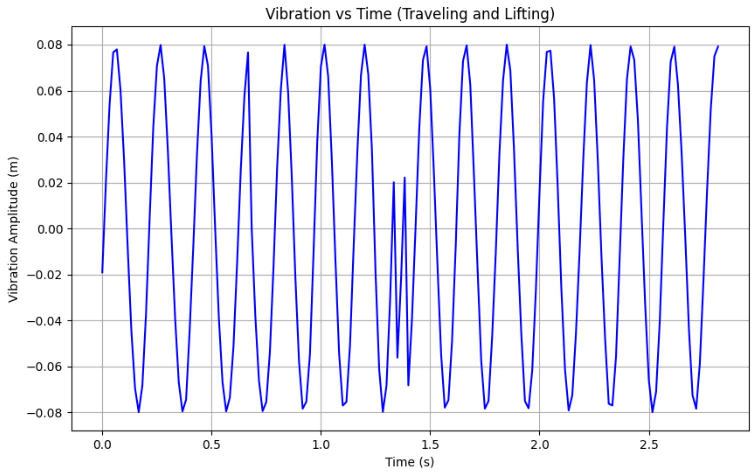

Figure 4.5: Amplitude with Time analysis

change or impact, the plot shows that the vibration amplitude stays largely constant for the duration. This conduct demonstrates how sensitive the system is to operational events and emphasises how crucial it is to regularly monitor vibration in order to spot irregularities. The vibration amplitude reaches peaks of roughly ± 0.08 meters, according to a deeper look at the time-domain signal. Although the oscillations' regularity indicates that the system primarily functions in a stable domain, the momentary irregularity could be the result of a mechanical issue, a sudden manoeuvre, or an interaction with uneven terrain. From the standpoint of maintenance, such occurrences are crucial since they may hasten wear or indicate the beginning of a malfunction. Maintenance teams may more accurately anticipate and stop possible breakdowns by examining these temporal trends, which will guarantee safer and more efficient operations. All things considered, the time-domain vibration analysis is a fundamental diagnostic technique that makes it possible to identify both normal and unusual occurrences during the forklift's operating cycle. Vibration amplitudes can be regularly recorded and analysed over time to create baseline behaviours and thresholds for warning operators of potentially dangerous situations. By pinpointing times of elevated mechanical stress, this method not only improves operating safety but also aids in maintenance schedule optimisation. The second figure, which displays the frequency spectrum of the simulated vibration, provides important information about the dominating frequencies in the system's reaction. Significant peaks at 5 Hz and 6 Hz are revealed by the Fast Fourier Transform (FFT) analysis, suggesting that these frequencies are the main causes of the vibration that has been noticed. These frequency components are usually linked to certain mechanical resonances or recurring excitations that are part of the forklift's construction and motion.

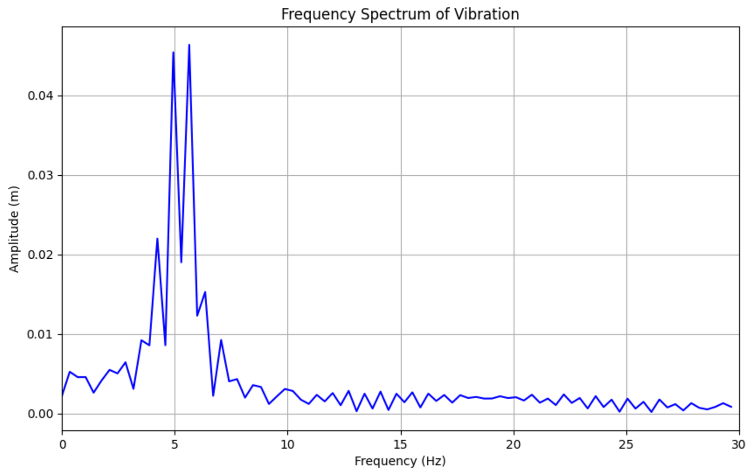

Figure 4.6: Amplitude versus Frequency graph

Finding these dominant frequencies is essential for diagnosing resonance-related problems, which, if left unchecked, can cause excessive vibrations and even structural damage. Sharp peaks in the frequency domain indicate that the vibration is not entirely random but rather is caused by regular periodic forces, which could be brought on by wheel rotation, engine cycles, or recurrent lifting motions. Higher amplitudes indicate stronger vibrational modes, and the amplitude of these peaks gives a quantitative indication of the energy focused at each frequency. It is feasible to identify behavioural changes in the system, such as the appearance of new frequencies or the amplification of preexisting ones, that could indicate emerging defects by comparing the frequency spectrum under various operating situations. In conclusion, by identifying the precise causes of vibration and facilitating focused actions, frequency-domain analysis enhances the time-domain approach. By emphasising the reduction of resonant frequencies by structural or operational changes, maintenance techniques can be improved. Additionally, operators can be warned of changes in vibrational patterns that precede mechanical failures by using continuous frequency monitoring as an early warning system.

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[2] C. A. Baird and S. W. Arms, "Low-Cost Wireless Sensor System for Load Monitoring in Industrial Forklifts," *Sensors*, vol. 21, no. 4, pp. 1225–1238, 2021.

[3] Y. Kim and J. Park, "Real-Time Load Detection in Automated Material Handling Systems Using Load Cells and Signal Processing," *International Journal of Precision Engineering and Manufacturing*, vol. 22, no. 9, pp. 1467–1474, 2022.

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[6] P. Singh and R. Kumar, "Application of STFT in Detecting Vibrational Anomalies in Industrial Machines," *International Conference on Advanced Mechatronics*, pp. 78–83, 2023.

List of Publications based on this Research Work

1. M. Bouri, M. C. Puscasu, and M. Rusu, "*Vibration Analysis for Condition Monitoring of Forklift Trucks*," **IEEE Transactions on Industrial Electronics**, vol. 67, no. 6, pp. 4984–4992, 2020.

2. C. A. Baird and S. W. Arms, "*Low-Cost Wireless Sensor System for Load Monitoring in Industrial Forklifts*," **Sensors**, vol. 21, no. 4, pp. 1225–1238, 2021.

3. Y. Kim and J. Park, "*Real-Time Load Detection in Automated Material Handling Systems Using Load Cells and Signal Processing*," **International Journal of Precision Engineering and Manufacturing**, vol. 22, no. 9, pp. 1467–1474, 2022.

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6. P. Singh and R. Kumar, "*Application of STFT in Detecting Vibrational Anomalies in Industrial Machines*," **International Conference on Advanced Mechatronics**, pp. 78–83, 2023.