Ministry of Physical Infrastructure and Transport

National Road Safety Council

Singhadurbar, Kathmandu

FABRICATION AND PERFORMANCE EVALUATION OF PROVISION OF WEIGHING SENSOR IN BUS AND TRUCK

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A study conducted by

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Singha Durbar, Kathmandu, Nepal

FINAL REPORT

FABRICATION AND PERFORMANCE EVALUATION OF PROVISION OF WEIGHING SENSOR IN BUS AND TRUCK

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LIST OF ABBREVIATION

BoQ	Bill of Quantity
CPS	Centre for Pollution Studies
DOR	Department of Road
GDP	Gross Domestic Product
HMI	Human Machine Interface
IoE	Institute of Engineering
MoPIT	Ministry of Physical Infrastructure and Transport
O&M	Operation and Maintenance
QRDC	Quality Research Development Centre
SDG	Sustainable Development Goals
SNH	Statistics of National Highway
TU	Tribhuvan University
VAT	Value Added Tax
VFTC	Vehicle Fitness Testing Centre

CHAPTER ONE: INTRODUCTION

1.1 Background

Widening the road network in Nepal has been a great challenge and impactful factor in the socio – economic development of the country. The development of the road network and maintenance is dated back to 2007 when they constructed and maintained roads in Kathmandu valley by the office named 'Botokaj Goswara'. The major and memorable work in the road development in Nepal was done by the Public Works Department in 2007 that was the construction of Tribhuvan Rajpath currently known as East – West highway. Till date it is the longest highway in Nepal runs from the east and touching the west border of the country. There are 80 national highways developed in Nepal covering the road length of 14,913 km as per report SNH 2020/21.

With the development of technology and roads, different parts of the country have become accessible. Despite the reduced travel time, the road accident rate has been greatly raised by this. Nearly 13,000 highway and road accidents were recorded by the World Bank in 2019, with over 2,700 fatalities and 10,000 severe injuries. Moreover, the economic impact of road accidents has multiplied by three since 2007 and now makes up 1.5% of the GDP. Numerous factors contribute to road accidents, such as inadequate road conditions, outdated vehicles without safety precautions or design flaws, overloading and traffic violations. Driver-related accidents are responsible for 60% of fatal accidents. Drivers may lose control and cause severe harm to their vehicles and staff due to the lack of clearance in front and back and overloading. Prior to the implementation of road safety as an SDG 3 Good Health and Well-Being, the Government of Nepal set aims to reduce road accident deaths by 50% by 2020.The government's primary challenge is ensuring road safety, even though their goal was not achieved. In 2013, the Nepalese Ministry of Physical Planning and Transport Management drafted its Road Safety Action Plan (2013 – 2020). The Nepal Road Safety Action Plan (2013-2020) and the World Bank's "Delivering Road Strategy" are jointly formulated to highlight five pillars that can contribute to safer roads in Nepal. These pillars are:

- Pillar 1: Road safety management
- Pillar 2: Safer Road and mobility
- Pillar 3: Safer vehicle
- Pillar 4: Safer Road users
- Pillar 5: Post-crash response

In regards to these five pillars the use of vehicle safer accessories can help in decreasing the road accidents like other pillars. Hence, Ministry of Physical Infrastructure and Transportation is conducting a pilot study to increase the safety of the road by installing weighing sensors within the vehicle.

1.2 Weight sensor

Weighing sensors or load cells are transducers that convert force into measurable electrical output. Among the various types of force sensors, strain gauge load cells are the most prevalent. A load cell converts mechanical force into digital units that can be read and recorded by the user. Various variations exist in the inner workings of a load cell. There are also hydraulic load cells, pneumatic load cell and strain gauge loading.

Load cell designs can be distinguished according to the type of output signal generated (pneumatic, hydraulic, electric) or according to the way they detect weight (bending, shear, compression, tension, etc.)

1.2.1 Hydraulic load cells

One of the common types of the load cells is hydraulic load cells. These devices are used to measure load or force which act on the principle of hydraulics i.e., change in pressure. The basic components of a hydraulic load cell include a piston, cylinder, and hydraulic fluid. When the force is applied to the piston, it compresses the hydraulic fluid, leading to the change in pressure. This change in the pressure is measured and is converted to the corresponding the force or weight reading. Different types of load cell designs can be created based on the output signal generated, such as pneumatic, hydraulic or electric, and the way the weight is detected (such as bending over shear, compression, tension, etc.). This type of load cells is mainly used where there is need of the precise and robust force measurements

1.2.2 Pneumatic load cells

Devices which are designed to measure force or weight using pneumatic or simply air or gas pressure as its sensing element, is defined as the pneumatic load cells. It operates based on the principle of Boyle’s law, which states that the pressure of given mass of gas is inversely proportional to its volume, assuming the temperature remains constant. When the sensing element is exposed to the applied force, it changes the volume of compressed air or gas. This change in volume ultimately results in the corresponding change in the pressure, which is measured and converted into force or weight measurement. The force-balance principle is also applicable to pneumatic load cells. The use of multiple dampener chambers in these devices enables them to achieve greater precision than hydraulic devices. The use of pneumatic load cells is widespread in industries that prioritize safety and cleanliness when measuring small weights. The load cell's inherent explosive nature and inability to handle temperature variations are the advantages of this type of load cell.

1.2.3 Strain-gauge load cell

A strain gauge assembly is housed within the housing of strain cells, which converts the load acting on them into electrical signals. It operates based on the principle of strain, which is the deformation of a material in response to an applied force. The load cell's weight is determined by the voltage fluctuation observed in a strain gauge during deformation. When a beam or structural member is subjected to deformation by weight, the gauges are secured in place. The modern load cell has 4 strain gauges arranged in the Wheatstone configuration, with two of them typically present in tension and two in compression, and they are wired with compensation adjustments to improve their accuracy. The strain gauges' resistances will remain unchanged when the load cell is not under load. Under load, the strain gauge's resistance can vary causing a change in output voltage. The output voltage variation is measured and interpreted as read-only values by a digital meter.

1.2.4 Weight Estimator using Position Sensor

This type of sensor measures axle load using a pivot lever that is installed on a vehicle suspension. It generally involves the measurement of the displacement of an object under a known force and then applying the principle of the physics, commonly known as Hooke’s law. Hooke’s law states that the applied force is directly proportional to the displacement, giving the relationship between the force and its corresponding displacement. The sensor is mounted between the cargo bed (or the car frame) and the sprung axle. Sensor output voltage changes with the lever position. The position of the sensor is mapped to the loading of the leaf-spring suspension. A controller receives the reading of all the suspension systems of the vehicle. The sum of the load exerted in all the suspension provides the actual load of the vehicle. In this type, calibration is crucial for accuracy, and factors such as friction and non-linearity in the sensor may affect the precision. To accommodate this limitation, advanced algorithm and sensor fusion techniques can be employed for improved accuracy.

Further, a tracking device receives the signal from the sensor and transmits it to the fleet monitoring server for further data analysis.

1.3 Problem statement

In case of heavy-duty vehicles like truck and lorry, the overloading of the vehicles can have detrimental effects on the road safety, environmental sustainability and the integrity of infrastructure. Overloading can make the vehicle unstable as well as requires large force to apply the brake. This can cause skidding and can heighten the risk of severe accidents. It also has the disadvantage of exacerbating the wear and tear of the mechanical parts of the vehicle which results in decreased vehicle lifespan. In addition to it, some roads and bridges are sensitive to heavy load and may cause serious damage when vehicle carriage load exceeds the legal weight limits. The overloaded vehicles impose unwanted strain on the roads and bridges which in turn accelerates their deterioration and increases the maintenance cost. Overloaded trucks increase the fuel consumption that results in the higher emissions, which contributes to environmental pollution and climate change along with increasing the operating cost of the vehicle.

1.4 Objective

The main objective of the study is to install weighing sensor for increasing the road safety in Nepal. The study shall be the pilot project for the demonstration of use of weighing sensor to indicate the drivers regarding the overall load within the vehicle.

The specific objectives are

- To execute research to develop standard design for the installation of weighing sensors in the vehicle and accordingly display their output for notifying the drivers
- To install the weighing sensor and hence develop the working prototype
- To demonstrate the use of weighing sensor to measure the load carried by the vehicle and accordingly display the weight carried in an HMI screen
- To develop a user-friendly interface for operators of vehicles to effortlessly interpret and then respond to the information of load provided by the weighing sensors, for promoting driving practices that are safer.
- To develop the design and specification baseline of the system for future installation.

1.5 Limitation

The limitations of this project are enlisted as the following:

- Unsimilar design of the sensor linkages in order to accommodate the available chassis space
- Installation difficulty of sensors regarding the parallel placement in the front and rear axle
- Data is taken and measured in this project when the vehicle is placed in the levelled road and in static condition
- The test vehicle has the leaf spring as its suspension system

CHAPTER TWO: METHODOLOGY

The detailed methodology that shall be followed during the study "Provision of weighing sensor in truck (fabrication and performance evaluation)" will be done at Vehicle Fitness Center (VFC), Teku is shown in Figure 2-1.

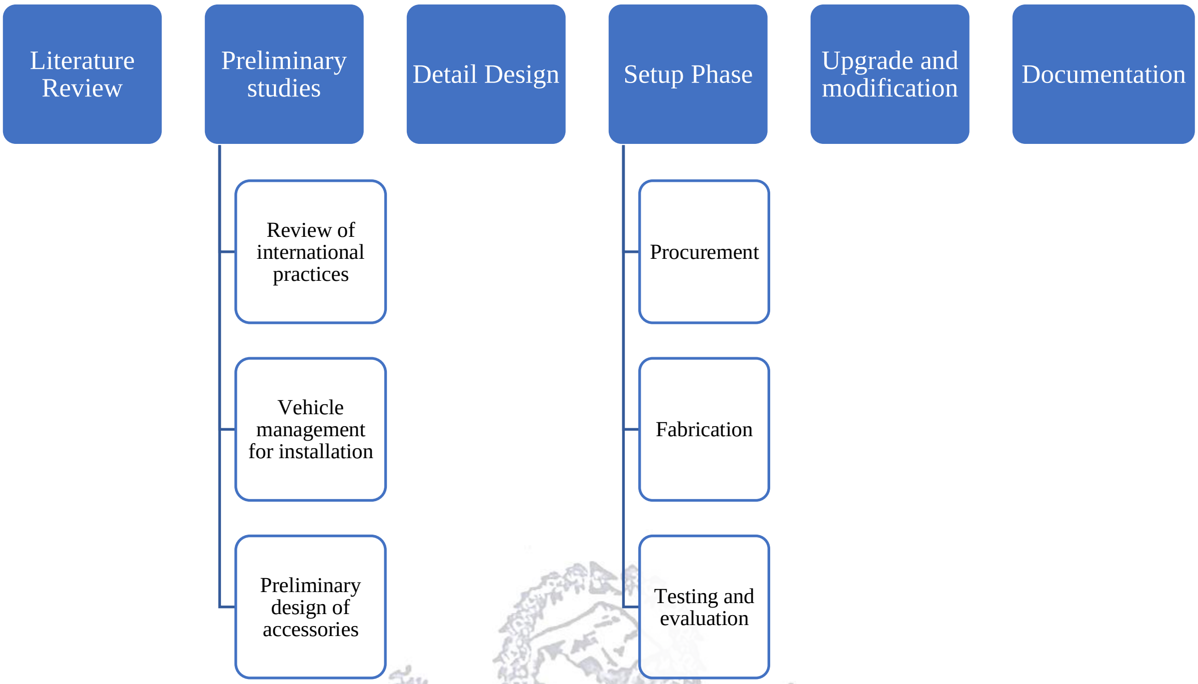

Figure 2-1: Methodological flowchart

2.1 Literature review

Initially literatures were reviewed to analyze the specifications, principles and protocols for developing a proximity sensor and load sensor that can be used in public transportation. To measure the clearance and weight of vehicles used in different countries, a comprehensive design was developed using peer-reviewed papers and journals. Also, various parts and their uses were thoroughly researched. Moreover, at this stage of the project all necessary approvals were managed.

2.1.1 Evolution of Weight Monitoring Sensors in Vehicles

Weight monitoring sensors have undergone significant evolution, driven by technological advancements and the growing need for efficient load management in the transportation sector.

- **Early Developments**: The initial concepts of weight monitoring involved mechanical scales and basic load measurement techniques. These early systems were manual and lacked precision but set the stage for future developments. For example, weighbridges and static scales were among the first tools used to measure vehicle weight, requiring vehicles to be stationary during measurement. These methods were time-consuming and prone to errors due to human intervention and environmental factors.
- **Technological Advancements**: The advent of electronic and semiconductor technologies in the mid-20th century led to more accurate and reliable weight monitoring systems. Strain gauge technology, in particular, revolutionized weight measurement by providing precise data on load distribution and total vehicle weight.

Strain gauges convert mechanical deformation into electrical signals, offering higher accuracy and reliability compared to mechanical methods.

- **Modern Weight Monitoring Sensors**: Recent advancements have seen the integration of microprocessors and digital signal processing in weight sensors. Modern systems offer high precision, real-time data collection, and robust performance in various environmental conditions. Technologies such as wireless communication and IoT (Internet of Things) integration allow for seamless data transfer and remote monitoring. These advancements have significantly improved the efficiency and accuracy of weight monitoring in vehicles.

2.1.2 Design Parameters and Guidelines for Proximity Sensors

The design parameters for proximity sensors in public vehicles are critical to ensuring their effectiveness and reliability. These parameters include detection range, environmental resistance, integration with vehicle systems, and user interface.

- **Accuracy:** Accurate weight measurement is fundamental for compliance with regulations and ensuring vehicle safety. Modern weighing sensors must provide precise data with minimal error margins. Factors such as sensor placement, calibration, and environmental conditions affect accuracy. For instance, the placement of axle load sensors must consider the suspension system's dynamics to avoid measurement errors caused by road vibrations and load shifts. High-precision sensors often use multiple sensing elements and advanced algorithms to compensate for such variations.
- **Environmental Resistance**: Weighing sensors must withstand diverse environmental conditions, including temperature fluctuations, humidity, and mechanical vibrations. Robust housing materials and protective coatings are essential to prevent damage and maintain sensor accuracy. Sensors designed for harsh environments often feature sealed enclosures to protect against dust, water, and chemical exposure. For example, stainless steel and reinforced polymers are commonly used materials for sensor housings due to their durability and corrosion resistance.
- **Integration with Vehicle Systems**: Seamless integration with existing vehicle systems is critical. Sensors should communicate effectively with vehicle control units and other monitoring systems, providing real-time data on load distribution and total weight. Communication protocols like CAN (Controller Area Network) and Modbus are widely used for this purpose, enabling interoperability between different vehicle systems and sensors. Proper integration ensures that weight data is accurately reflected in vehicle diagnostics and fleet management systems.
- **User Interface**: The Human-Machine Interface (HMI) should be user-friendly and designed to integrate with the vehicle's dashboard. It should provide clear and intuitive feedback, allowing drivers to monitor weight data and take necessary actions to ensure compliance and safety. Modern HMIs often feature touch screen displays with customizable dashboards that present weight information, alerts, and historical data in an easy-to-understand format. Additionally, HMIs can be integrated with mobile apps or cloud platforms for remote monitoring and data analysis.

2.1.3 Fabrication Techniques for Proximity Sensors

Fabricating weighing sensors involves advanced techniques to ensure precision and durability. Key aspects include material selection and manufacturing processes.

- **Material Selection**: The choice of materials significantly impacts the sensor's performance and longevity. High-grade materials such as stainless steel and reinforced polymers are commonly used to enhance sensor durability. These materials offer resistance to corrosion, mechanical wear, and environmental stressors. For example, stainless steel is preferred for its strength and corrosion resistance, making it suitable for outdoor and industrial applications. Reinforced polymers provide a lightweight alternative with excellent mechanical properties and resistance to environmental degradation.
- **Manufacturing Processes**: Precision machining and surface coating technologies are essential for producing high-quality sensors. Precision machining ensures that sensor components fit together accurately, reducing the likelihood of mechanical failure. Techniques such as CNC (Computer Numerical Control) machining and laser cutting are commonly used to achieve tight tolerances and intricate designs. Surface coatings protect sensor elements from environmental damage, extending their operational lifespan. Common coatings include anodizing, electroplating, and powder coating, each providing specific benefits such as enhanced wear resistance or electrical insulation.

2.1.4 International Standards and Best Practices

Reviewing international standards and best practices is essential to ensure the sensors' design and fabrication meet global safety and performance requirements.

- **ISO Standards**: The International Organization for Standardization (ISO) provides comprehensive guidelines for the design and testing of vehicle sensors. ISO 1496-1, for instance, outlines the requirements for containers and their associated equipment, which is relevant for ensuring the accuracy of weighing systems in transport vehicles. ISO 9001, focusing on quality management systems, ensures that manufacturers follow rigorous quality control processes, resulting in reliable and consistent sensor performance.
- **SAE Standards**: The Society of Automotive Engineers (SAE) publishes standards for vehicle sensors, including those for load and weight measurement. SAE J1939, which specifies communication protocols for in-vehicle networks, ensures sensor compatibility and reliability. Adherence to SAE standards guarantees that sensors can seamlessly integrate with various vehicle systems and comply with industry requirements for data communication and safety.
- **NTEP Certification**: The National Type Evaluation Program (NTEP) certification, issued by the National Conference on Weights and Measures (NCWM) in the United States, ensures that weighing devices meet stringent accuracy and performance criteria. NTEP certification is essential for sensors used in commercial transactions, ensuring that measurements are legally defensible and comply with regulatory standards.

2.1.5 Case Studies and Practical Applications

Analyzing case studies and practical applications of proximity sensors in public vehicles provides valuable insights into their real-world performance.

- **Urban Bus Fleets**: Implementing weighing sensors in urban bus fleets has shown improvements in load management and operational efficiency. These sensors help ensure buses do not exceed weight limits, enhancing safety and compliance with regulations. For example, a study conducted in London demonstrated that buses equipped with axle load sensors experienced a 15% reduction in overloading incidents, leading to lower maintenance costs and improved passenger safety.
- **Heavy-Duty Trucks**: Weighing sensors in heavy-duty trucks have proven effective in optimizing load distribution and ensuring compliance with weight regulations. These sensors provide real-time data, allowing for better decision-making and improved operational efficiency. In the United States, a large logistics company reported a 20% increase in route efficiency and a 10% decrease in fuel consumption after implementing weight monitoring systems across its fleet.
- **Freight Management**: Integrating weighing sensors into freight management systems allows for better tracking and distribution of cargo weight. This integration helps prevent overloading and ensures that cargo is evenly distributed, reducing the risk of accidents and improving fuel efficiency. A case study from a European logistics firm highlighted a 25% reduction in delivery delays and a significant decrease in vehicle wear and tear due to optimized load management facilitated by weight sensors.

2.1.6 Components and Specifications

The successful implementation of proximity sensors requires careful selection and specification of components. Key considerations include the sensor interface, control unit, and installation mechanisms.

- **Axle Load Sensor for Leaf Spring Suspension**: This type of sensor is crucial for accurately measuring the load on each axle. It must be robust enough to handle the stresses of heavy loads and provide precise data for load distribution analysis. Axle load sensors typically use strain gauges to measure the deformation of the leaf spring, translating mechanical stress into electrical signals. High-precision sensors can detect even minor variations in load, providing accurate data essential for maintaining vehicle stability and compliance with weight regulations.
- **Sensor Interface (Modbus)**: The Modbus communication protocol is widely used for sensor interfaces, providing reliable and standardized data exchange. Modbus supports easy integration with various vehicle systems, facilitating comprehensive monitoring and control. The protocol's flexibility allows for both serial (Modbus RTU) and network (Modbus TCP) communication, ensuring compatibility with different vehicle architectures and monitoring systems.
- **Control Unit with Touch Screen Display**: The control unit must be user-friendly and provide real-time data visualization. An intuitive HMI design enhances driver interaction and system usability, presenting weight data clearly and allowing for quick adjustments as needed. Advanced control units often feature customizable dashboards, data logging capabilities, and alarm systems to notify drivers of critical weight

conditions. Integration with GPS and telematics systems can further enhance fleet management by providing location-based weight data and enabling route optimization.

- **Fittings, Wiring, and Assemblage Mechanisms**: Proper installation of sensors requires high-quality fittings, wiring, and assemblage mechanisms. These components ensure that the sensors are securely mounted and function reliably under various conditions. The choice of fittings and wiring should account for the vehicle's operational environment, ensuring resistance to vibration, temperature fluctuations, and moisture. Installation mechanisms should also facilitate easy maintenance and replacement of sensors, minimizing downtime and ensuring continuous operation.

2.1.7 Authorization and Compliance

Ensuring necessary authorizations and compliance with regulatory requirements is a crucial aspect of the project. Key steps include regulatory approvals and testing and certification.

- **Regulatory Approvals:** Obtaining approvals from relevant transportation and safety authorities is essential for legal compliance. This process involves demonstrating that the sensors meet all applicable safety and performance standards. In the United States, the Federal Motor Carrier Safety Administration (FMCSA) oversees regulations for commercial vehicle weight compliance. Approval processes typically include rigorous testing of sensor accuracy, durability, and integration with vehicle systems. Ensuring compliance with FMCSA regulations helps prevent overloading, enhances road safety, and minimizes wear and tear on infrastructure.
- **Testing and Certification:** Rigorous testing and certification ensure the sensors meet industry standards for accuracy, durability, and reliability. Testing protocols include environmental simulations, mechanical stress tests, and long-term performance evaluations. Independent testing organizations, such as TÜV Rheinland or Underwriters Laboratories (UL), provide certification services that validate sensor performance against established standards. Certification from recognized bodies assures end-users of the product's quality and reliability, facilitating market acceptance and regulatory compliance.

2.2 Preliminary studies

The installation and testing of the vehicle sensor have been coordinated by a team of researchers working with the Ministry of Physical Infrastructure and Transport and the vehicle fitness center. The researcher has also examined the vehicle's design and found out where sensors could be placed. Ideally, sensors should be placed in areas where they are not easily detectable. The initial model of the gadgets was created to further identify the requirement in load sensing. Based on the preliminary design, detailed design of further components was done.

2.3 Detailed design

During this stage of work, the accessories' detailed design was accomplished. Detailed electromechanical design that exhibits each component from different angles was created using the specification of various components and preliminary design. SolidWorks software was utilized for the detailed design of mechanical designs and also the design of controller enclosures. The emphasis in the design was on the positioning of sensors and other electrical components. Each component was made easily accessible for repair and maintenance, without any direct visibility.

Automobile-grade sensors and accessories were identified and used for the design purpose. Axle load sensors were selected for determining the actual load on the vehicle on test and Modbus modules based on RS 438 serial communication architecture were selected to transfer data easily over long distances. Modbus is selected in industrial environments for its low sensitivity to noise because of the use of differential receivers and balanced drivers for resisting the external noises in the system. It also enables data to be sent through long distances which is up to 1200 meters. Moreover, the transmission rates given by the Modbus is over 10Mbps which is way higher than the traditional serial communication architectures.
For the choice of microcontroller of the system, Arm Cortex M3 was chosen for processing the signals provided by the position sensors and to send the output to the HMI unit for display. Arm Cortex M3 was chosen because of the good balance between the power consumption and and performance provided by the controller. It was selected due to its scalabity and flexibility to be integrated with wide range of applications in automotive and electronic fields. 32 bit architecture was chosen because it handled more data per clock when compared to 8 bit and 16 bit architectures.
The design included the hardware component and the software component of the system. UI/UX was also developed for the controller to track and monitor results of the testing. This was helpful in showcasing the capabilities of the system and also in formulating further courses of action.

2.4 Set-up phase

This was one of the most challenging phases of work and module-wise hardware testing was done before assembly. After confirming the proper working of each module integration of all the components was done. The main tasks performed in this phase of work are shown in tFigure 2-2.

Figure 2-2: Tasks performed during setup phase

2.4.1 Procurement

Based on the design components were identified, and specification was made along with the required quantity of components. Different vendors were consulted during the component procurement phase. Some of the components were available in the local market but the sensors needed to be brought from abroad. Components not available in local markets were located in China. Different vendors listed in our organization were contacted to supply the required components. Based on the nature of components and phases of development two slabs were made for procurement. Few vendors were ready to supply the components so we published public notice for the procurement. We received quotations from four different vendors and we selected the one to award the purchase order based on the price and specification of the items offered.

Fabrication experts from our team confirmed the specifications of the supplied components. We were able to acquire all the required components for the project from two different vendors in two phases. The specifications of the acquired components are listed in the Table 2-1.

Table 2-1: Specification of procured goods and components

S.N.	Particulars	Specification	Reference Model
1.	Axle load Sensor for Leaf spring suspension	1. Position sensor designed for measuring axle and cargo load on vehicles with leaf spring suspension 2. Measures the distance travelled by the leaf spring to estimate the loading of the vehicle Specs: • Output voltage range, V: 1.5 to 3.46 • Absolute error of output voltage generating, mV, not more than ±80 • Supply voltage range, V: 8 to 32 V • Ingress Protection Rating: IP55 or above • Weight, g, not more than: 1000g	GNOM DDE
2.	Sensor interface	8 channel RS485 Sensor Expander Modbus /RS485 communication compatible interface with 8 ports DC 5 to 24V input Low power module with options to integrate with the controller or function as a stand-alone system	Customized for the system
3.	Control Unit	• Embedded Controller of 32 bit or above • Digital display: 7 inches with touchscreen • Color: 16.7M(16777216) colors • Panel Type: IPS • Viewing Angle: 85/85/85/85 (L/R/U/D) • Active Area (A.A.): 94.20mm (W)*150.72mm (H) • Visible Area (V.A.): 94.60mm (W)*151.12mm (H) • Resolution: 800*1280 Pixel • Backlight: LED • Brightness: 300 nit	Customized controller
4.	Wireless module	• Quad-band 850/900/1800/1900MHz • GPRS class 2/10 • Input Voltage: 9V-12V DC • Control via AT commands (3GPP TS 27.007, 27.005 and SIMCOM enhanced AT command set) • Configurable baud rate • Built-in SIM Card holder • Built-in Network Status LED	SIM800A

2.4.2 Development and testing

The Software portion was divided into sensor interfacing and display module. The sensor interfacing was done using Modbus protocol. For the display module the UI/UX was developed in Figma and the design was later programmed into the display module using the interface provided by DWIN instruments.

The sensor interface was programmed in an embedded controller which acted as a bridge between the sensor and the display unit.

The hardware was further prepared to be assembled in a single enclosure which could be mounted in the vehicle itself. Sensor calibration could be done in each vehicle since we have not identified the vehicle series for the application of the sensor system. For this stage it can be programmed to be placed in any generic vehicle.

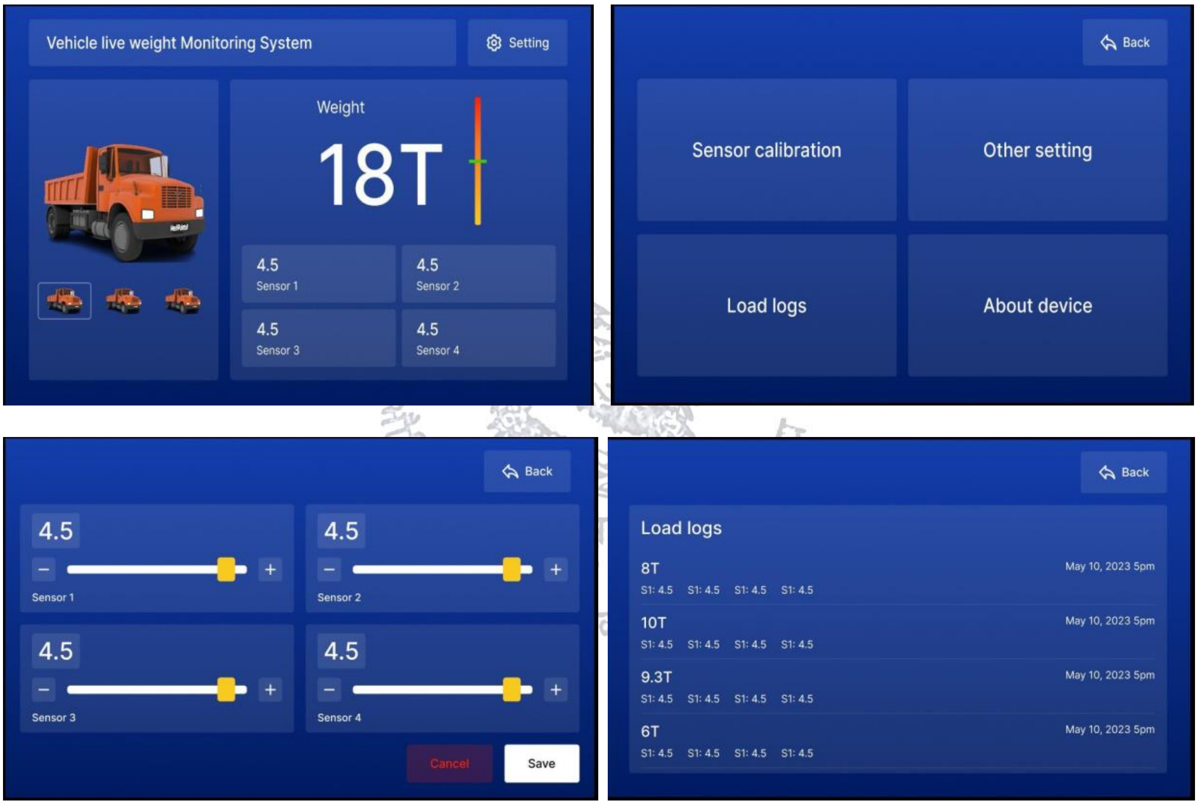

Figure 2-3: User interface for the system

Figure 2-3 shows the development of software side of the user interface which is developed and implemented in the controller.

2.4.3 Fabrication and installation

Fabrication mainly included the circuit fabrication and assembly of the controller. 3D Printing was utilized to manufacture some complex parts. Sensor placement units were fabricated to fit the vehicle suspension system. Figure 2-4 shows the controller designed and manufactured for the weight sensor.

Figure 2-4: Controller

To ensure the quality and track the progress of fabrication along with the cost of the project, earned value analysis was conducted in various steps. Component selection and design were iterated to ensure the reliability and cost effectiveness of the overall system so large-scale implementation and product acceptance probability would increase. The safety of the manpower was always our priority and measure to ensure minimize accidental hazards were taken. The design was done keeping in mind the manufacturing capabilities of the Nepalese market so that the device would be manufactured in Nepal for future usage.

2.5 Upgrade and modification

Finally, the weighing sensor have been tested for the accuracy, reliability and durability in different conditions. The test results were then evaluated to develop the baseline criteria for these accessories. The researcher modified and upgraded the system for better performance and reliability while reducing the cost. The modifications have been done in coordination with Ministry of Physical Infrastructure and Transport and other stakeholders.

2.6 Documentation

All the information regarding the design, testing and modification along with cost benefit analysis have been utilized to develop the final report. The revised final report shall be submitted after incorporating comments, feedbacks and suggestions from various stakeholders. The findings of the research along with demo of weighing sensor in trucks shall be presented among stake holders.

CHAPTER THREE: RESULTS AND DISCUSSION

3.1 Preliminary design output

Figure 3-2 shows the preliminary design for the proposed weight monitoring system. The proposed design makes use of four weight sensors which are attached to the upper side of the axle just beside the wheels. There are two axle load sensors at the front (Sensor 1 and Sensor 2) and two axle load sensors at the back (Sensor 3 and Sensor 4). The type of axle load sensors used depend on the type of suspension of the vehicle. These sensors shall help deduce the weight of the load being carried and display the value in the display unit, which is a part of the control unit as shown in Figure 3-1.

Figure 3-1: Controller showing the loading condition of the vehicle in real time

The working of the controller, sensor and display modules are confirmed in different stages. Road testing is set to be carried out once the suitable vehicle for testing is made available. The road testing was carried out in coordination with the vehicle testing center at Teku.

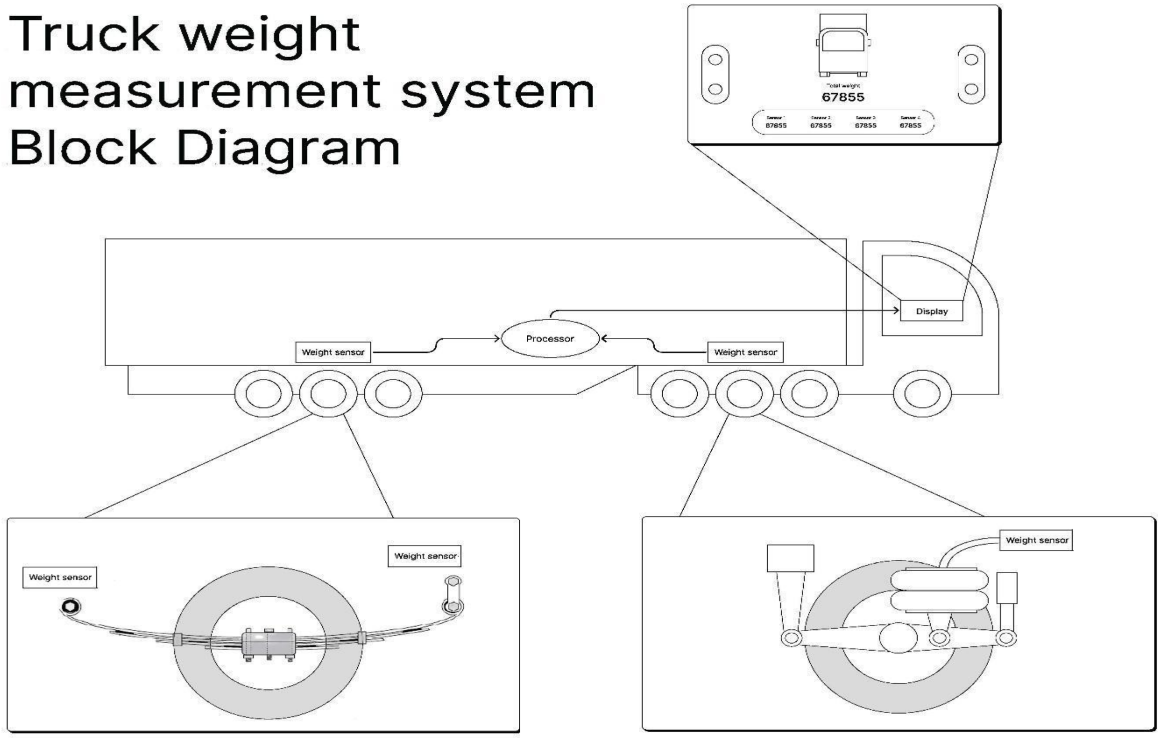

Figure 3-2: Preliminary design of the weight monitoring system

The major components of the design include:

3.1.1 Arm Cortex-M3 Microcontroller

ARM Cortex-M3 microprocessor, is a high-efficiency microcontroller that is widely utilized in designing electronic circuits and other embedded applications. It is based on the ARMv7-M architecture, which is known for its high performance, energy efficiency, and user friendliness. The Cortex-M3 is intended for applications that need cost-effectiveness and low power consumption, making it appropriate for a wide range of industries such as automotive, industrial automation, and consumer electronics. One important innovation is the Thumb-2 instruction set, which improves code density and performance. The CPU has a three-stage pipeline and supports hardware division, single-cycle multiplication, and quick interrupt handling, which all improve real-time performance. Furthermore, it has a nested vectored interrupt controller (NVIC) for efficient and flexible interrupt handling, which is required for responsive embedded systems.

3.1.2 Position Sensor

This type of sensor uses displacement of leaf spring to determine the weight of load placed in the vehicle. This sensor is preferred for the assignment as its output signals are stabilized and do not depend on voltage supply and the output signal is linearly dependent on the angular rotation of the lever. The benefits of using position sensors are:

- Design Specificity: The position sensor was particularly designed to measure axle and cargo load on cars with leaf spring suspension, making it ideal for this application.
- Distance Measurement: It properly measures the distance traveled by the leaf spring to establish the vehicle's loading, resulting in exact weight estimations.

- Durability and Reliability: These sensors are designed to endure the extreme conditions seen in automotive applications, assuring long-term dependability and durability.
- Real-Time Monitoring: Allows for real-time monitoring of the vehicle's load, which is critical for meeting safety regulations and avoiding overloading.
- Simple Integration: The sensor may be easily integrated into current vehicle systems, needing only minor structural adjustments.
- Great precision: Provides great precision in load measurement, guaranteeing that the data collected is dependable.
- Cost-Effective Solution: Provides a cost-effective solution for load measurement that does not require sophisticated circuitry or extra power supply.
- Maintenance-Free Operation: Designed to need minimal maintenance, eliminating the need for periodic calibrations or adjustments.
- Enhanced Safety: By giving accurate load readings, the position sensor improves vehicle safety by eliminating overloading and related dangers.
- Data Integration: The position sensor's output may be readily combined with other vehicle management systems, such as telematics and fleet management software, to provide extensive monitoring and reporting.
- Scalability: Suitable for a broad range of vehicle types and sizes, including light-duty vehicles and heavy-duty lorries, allowing for scalability throughout fleet operations.

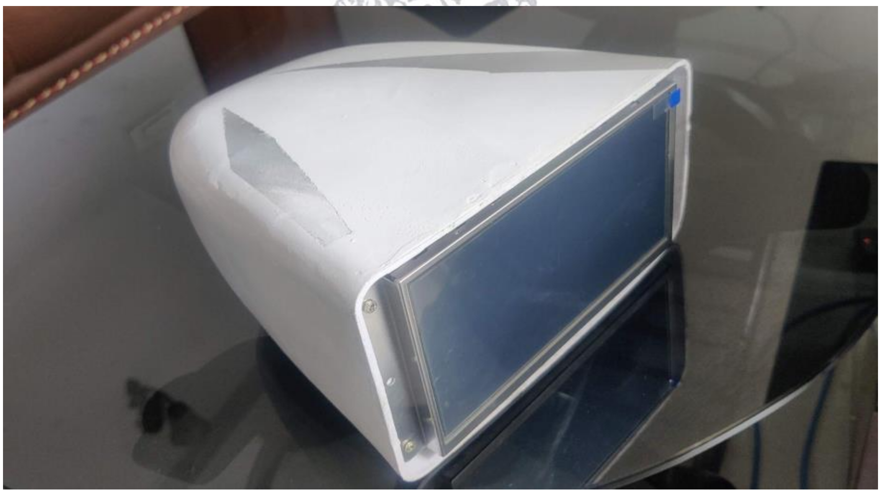

Figure 3-3: Controller used for the system

3.1.3 Modbus

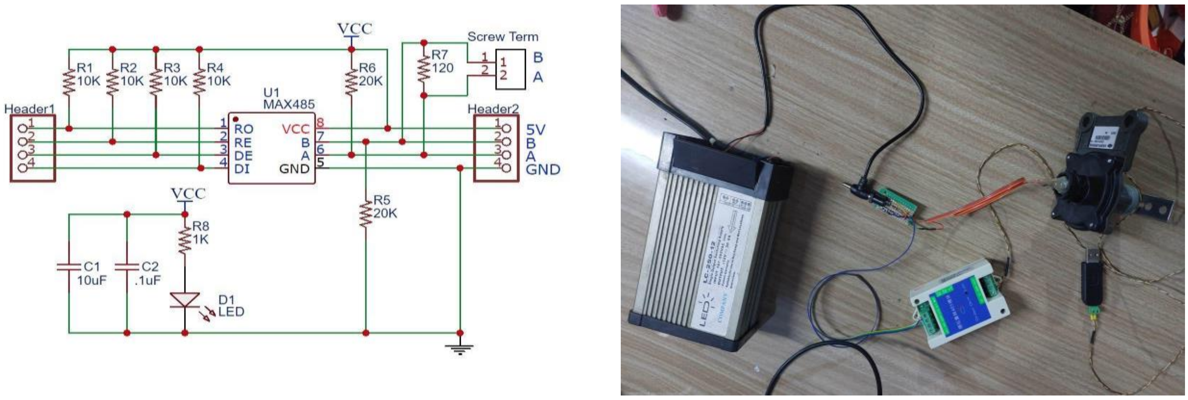

Figure 3-4: Modbus circuit design and hardware connection

Modbus RS485 is a widely used serial communication protocol in automation and control systems, especially in industries.RS485 is a standard for serial communication transmission of data whereas Modbus is a protocol that defines the message structure and communication rules used within the RS485 network. The coalition of these two technologies is widespread because of the ability of Modbus RS485 to enable seamless communication among the controllers and their corresponding actuators. It is used in wide variety of applications because it caters to both master-slave communication architecture and peer-to-peer communication architecture. Figure 3-4 shows the Modbus communication testing after connecting the sensor and controller. The Modbus hardware was configured to transfer the analog signal received from the transducer of the position sensor into digital signal and passing the message over to the controller in RS485 protocol. One Modbus module is capable of handling multiple sensors too, which is useful in interfacing other sensors that will be placed in adjacent suspensions.

3.1.4 Control Unit/HMI

Human Machine Interface (HMI) consists of the display module and may be with the embedded controller buttons or keypads. HMI is equipped with a 7-inch display with all of the control system components encased behind it. The control covers a signal conditioner, data logger, and storage along with the cloud communication system. The cloud communication channel is placed in the controller but the cloud connectivity is left open for further development. The display of the control unit is designed in such a way that the drivers will be able to identify the necessary data immediately. The screen shall display the weight generated by the carried load on each axle of the truck and average load. The controller also features a section to show the safety scale based on the vehicle specification. Overloading limits can be set in the controller which is shown in a linear scale in the dashboard of the controller.

Figure 3-5: Human Machine Interface (HMI)

3.1.5 Cloud Connectivity

In the proposed system, data generated by vehicle position and loading condition is securely saved in cloud-based data storage services. These services, including Amazon S3, Google Cloud Storage, and Azure Blob Storage, which provide dependable and scalable options for handling massive amounts of data. For our system, we use Amazon S3 service because it provides the most durable storage in whole of cloud platform. It also has low data latency which in turn increases the response of our system. Data transmitted from the vehicle's onboard systems is encrypted and securely transported to the selected cloud storage site using industry-standard protocols to maintain data integrity and confidentiality. Once in the cloud, the data is structured and classified based on established criteria, making it conveniently available for further analysis and retrieval. Furthermore, Amazon S3 cloud storage solutions include features like redundancy and data replication, which protect against data loss and provide high availability.

3.2 Output on test vehicle

After the completion of system testing was done in a vehicle made available by the consultant itself. Vehicle specification and user manual were referred to for the loading capacity. For the spring constant of the vehicle under test experimental value was used.

Displacement caused by the rated load in the vehicle was noted to be the maximum loading condition. The lever of the load sensor was adjusted to play between the minimum and the maximum displacement. Calibration was done after placing known load in the vehicle and measuring the respective displacement.

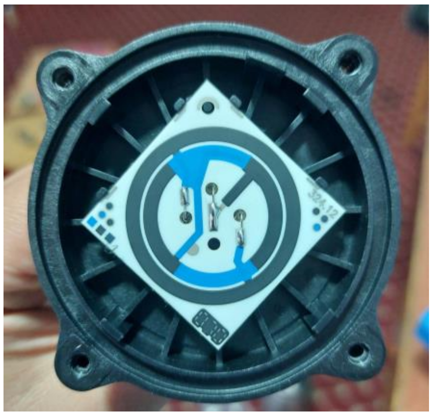

Figure 3-6: Sensor

The vehicle under testing is described as below:

Vehicle under test: Tata 709 truck

Maximum loading capacity: 695 Kg (As stated on the official user manual)

Angular movement based on displacement: 40 degrees (the sensor has maximum working angle of 60 degree)

The blue section of the load sensor is not usable for measurement of the angle due to displacement.

Figure 3-7: Vehicle used for testing

The general circuit of the sensor to the display is shown in the Figure 3-8.

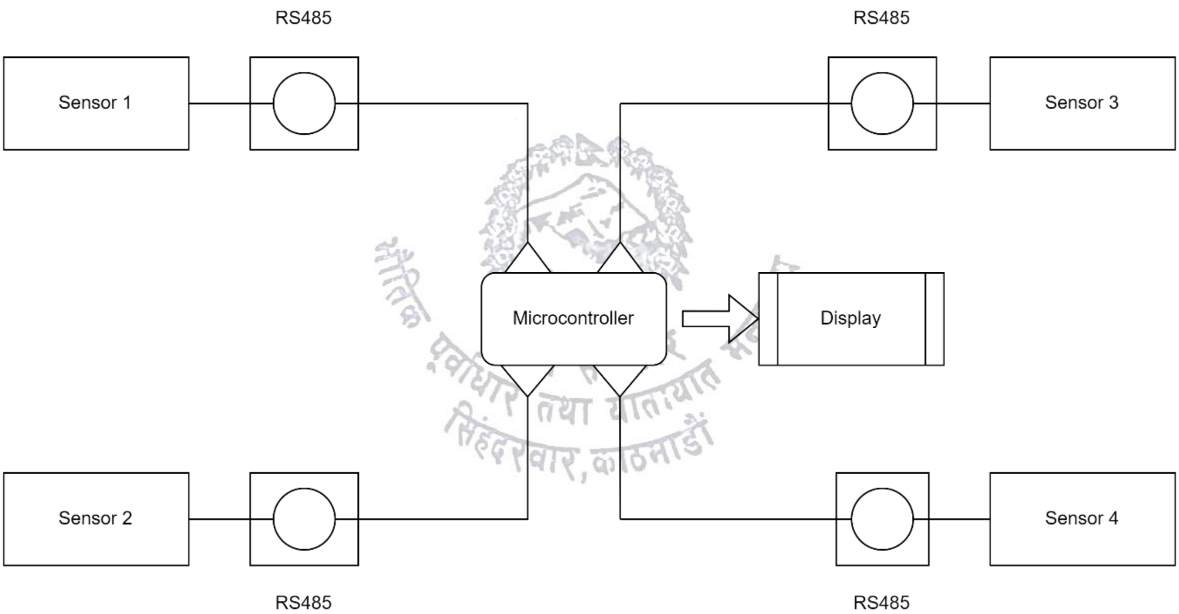

Figure 3-8: General circuit representation of sensor and display

The sensor raw reading is sent to the Modbus/RS 485 which converts it into the digital signal. Each sensor has its own RS 485 for the converting the analog to digital data. These digital signals from four sensor are received, analyzed and averaged out by the microcontroller. Then the processed result is transferred to the display, along with the necessary message or information as shown in the Figure 3-8.

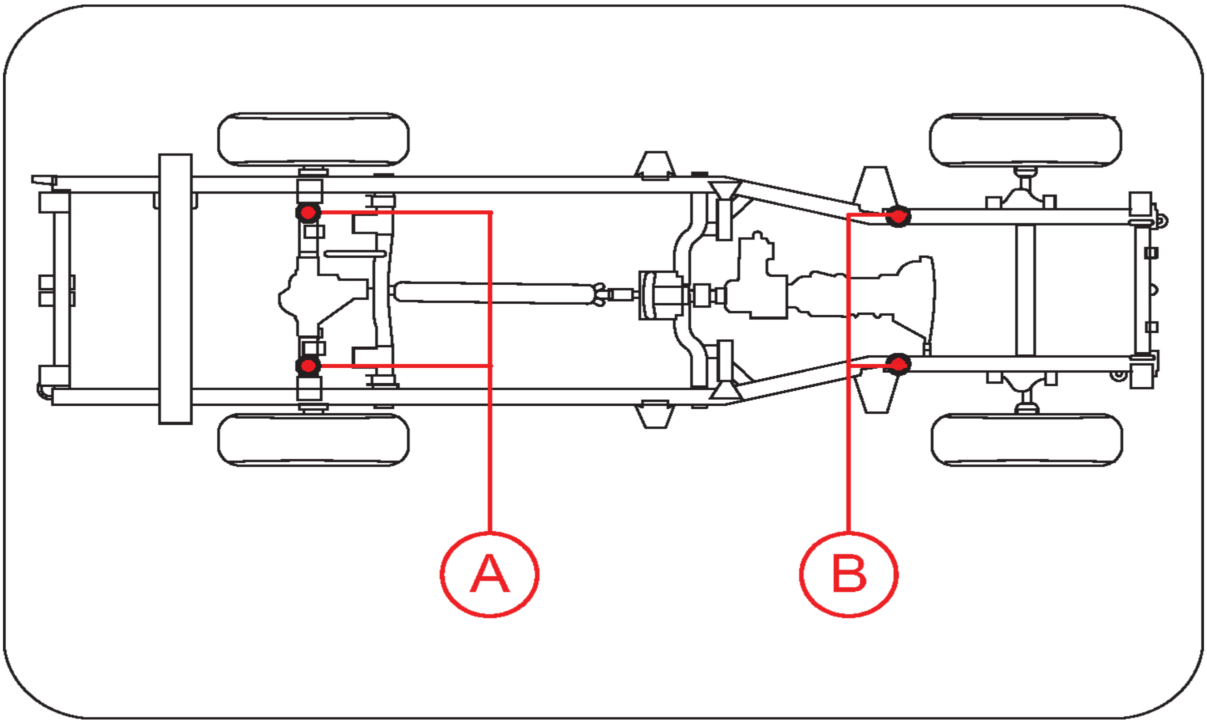

Figure 3-9: Placement of sensors

Figure 3-9 shows the location of Weight sensor in the vehicle (Front 'B' and Rear 'A'. Total of four sensors are placed in the vehicle to capture the displacement of each suspension. The individual displacement is mapped to respective weight and the sum of all weight was represented as overall vehicle payload.

Figure 3-10: Uncalibrated results

Figure 3-10 shows the uncalibrated result since the displacement coefficients were initially calculated for Truck. The same sensor and control unit were later placed in the vehicle under test which has significantly low payload. But comparing the change of payload, the displacement in suspension was not proportional.

So, we adjusted the lever length to match the angular displacement between maximum and minimum. Utilizing the broader angular displacement provided more resolution in calculation.

After adjusting the displacement coefficients (values can be adjusted from the sensor calibration page of the controller), actual payload of the vehicle was shown.

3.3 Working methodology

In the weight monitoring system, the sensors are continuously sensing the load carried by the vehicle, but it is calibrated in such a way that the sensors shall send the signal to the control unit after a certain time interval (the time interval shall be at least 5ms). In the control unit, firstly, the received signals are filtered by the signal conditioner through the use of either a PID controller or a fuzzy logic. Here, the external noise and disturbances are filtered out and only the actual signal is passed to the next step where the signal is manipulated to get the actual weight carried by the vehicle. This data is displayed in the screen and stored in the system itself as well as in a cloud storage for remote accessing. The electric circuit diagram for the system is shown in Annex I.

A sensor setup 3D model was made as shown in Figure 3-11. The setup was such that the translational motion of the truck axle was converted to rotational motion of the sensor arm.

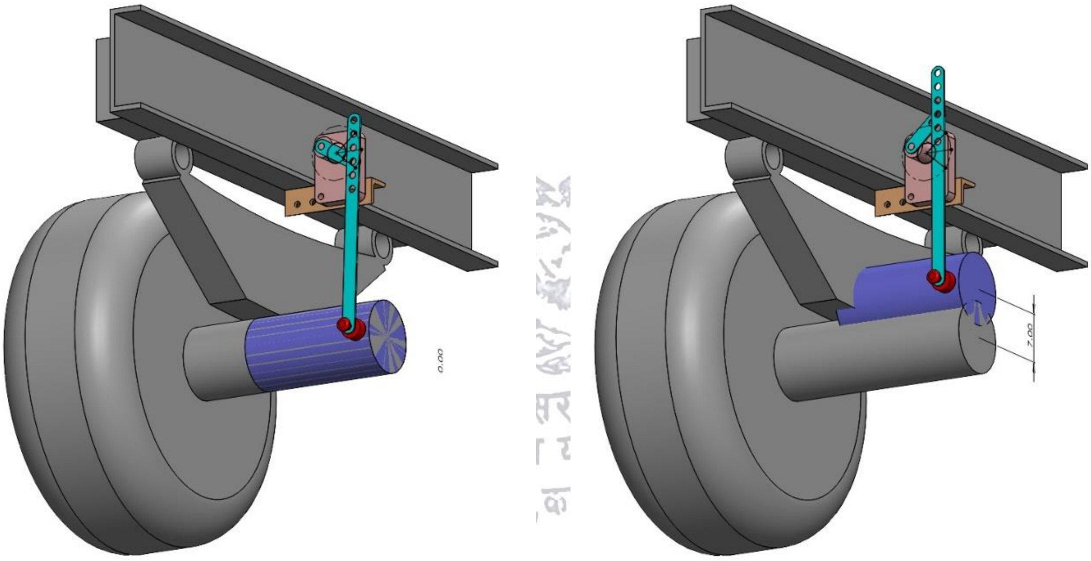

Figure 3-11: 3D model for the sensor installation

At first due to limited documentation of the sensor we needed to find out the degree per count of the sensor. This was done by rotating the sensor arm to a known angle and dividing the angle by the number of counts displayed by the sensor. This was cross-checked by rotating the sensor to another known angle. Now we could convert the sensor count to angle. Further we used some geometrical equations to convert the angle moved by the sensor arm to linear distance moved by the axle. The geometry as well as the equations used are shown below. Now after we could get the linear displacement of the axle, we used Hooke's law.

Let S_i be the sensor raw readings where i = 1,2,3,4 and θ_i (for i =1,2,3,4) be the corresponding angular displacements. In order to find the displacement x_i, we have to perform the conversion in the following sequences as:

S_i ------------------------> θ_i ---------------------------> x_i

1) S_i ----> θ_i

$$\theta_i = S_i \times \frac{90}{4640} \times \frac{\pi}{180}$$

where (90/460) is the proportional term and 90° corresponds to the value 4640.

2) θ_i ----> x_i

Since the geometries of front and back wheel sensors are different, this conversion takes place in two steps:

a) For front

$$x = \frac{-b \pm \sqrt{b^2 - 4 \times a \times c}}{2 \times a}$$

where a = 1, b = -2xsin(θ) and c = $x^2 - y^2 + 2xz\cos(\theta)$

b) For back

$$x = \frac{-b \pm \sqrt{b^2 - 4 \times a \times c}}{2 \times a}$$

where a = 1, b = -2xsin(θ) and c = $x^2 - y^2 - 2xz\cos(\theta)$

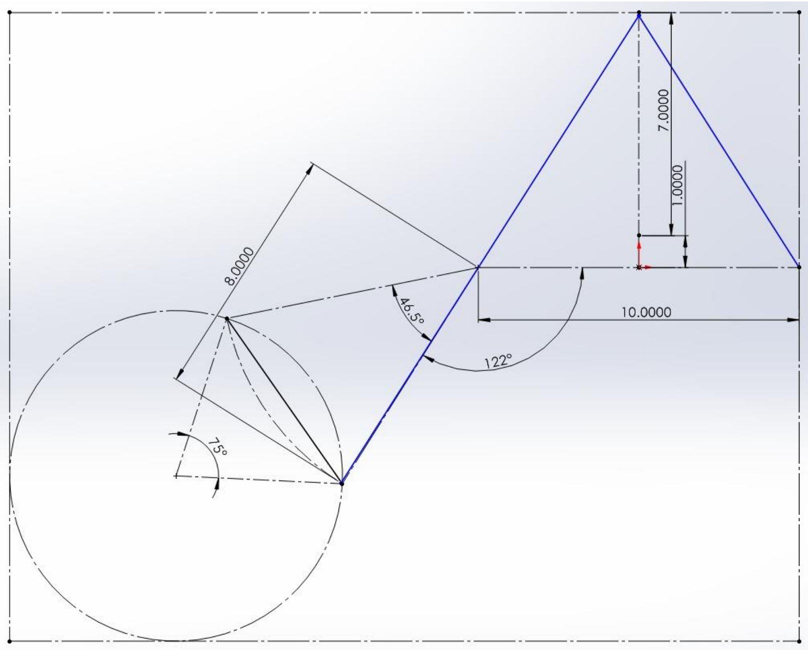

Figure 3-12: Line diagram of linkages in sensor

The arrangement of linkage used for the sensor to transfer the vertical displacement of leaf spring to the angular displacement of the sensor arm is shown in the Figure 3-12.

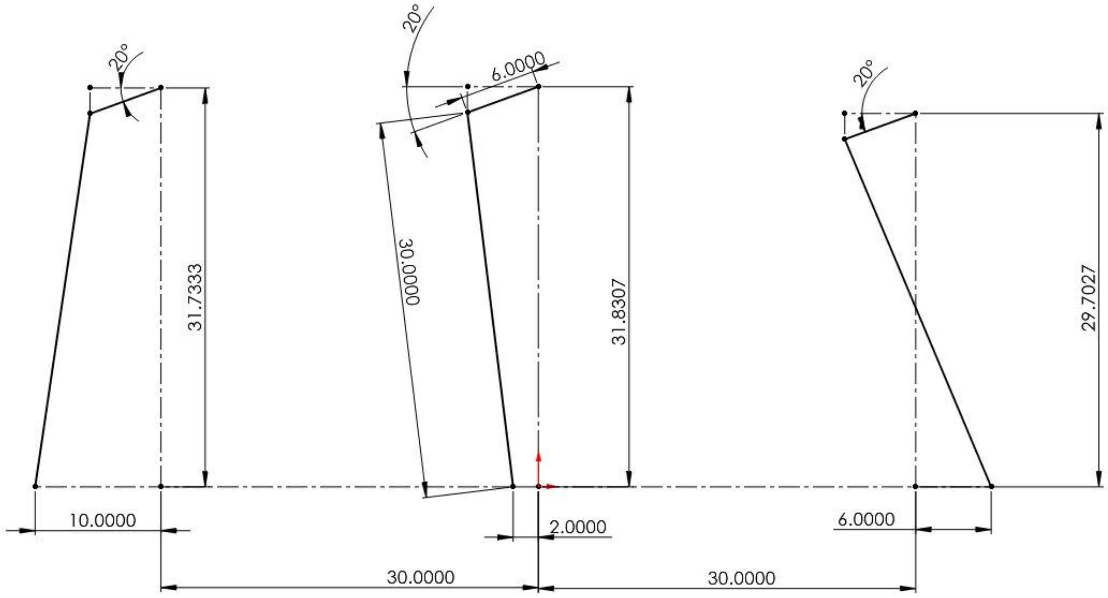

Figure 3-13: Conversion of angular distance to linear distance

In Figure 3-13, first diagram shows the linkage arrangement of the rear axle sensors whereas last two are the arrangement of the sensor linkage for the front axle. The linkage design is different from each other because of the clearance for sensor installation in the truck body. To accommodate the space remained in the truck body, the length of the linkages is different and orientation of force transmitting linkage is also different. The linkage arrangement of the sensor located in the rear axle is shown in the Figure 3-14.

Figure 3-14: Installation of the sensors in the vehicle

3.4 Sensor Calibration

In order to calibrate the sensor, the truck was filled with the known weight of water in its back cargo holder and was emptied to certain mass until cargo holder was completely emptied in order to change and record the change in sensor. The truck was moved to different position to find the leveled surface so that the change in sensor was only due to the weight change. The calibration was done in three times in three different locations and the sensor readings were recorded by experts through careful observation and are given in the Annex II. The formula given in section 3.3 was used to convert the sensor reading to mass estimation using MATLAB software. The source code, which is used to convert raw data to the sensor reading, is given in the ANNEX III. Then those code is used to generate different graphs in order to observe their nature with change in the weight and are described as follows.

3.4.1 Raw sensor reading Vs Mass

The back right (BR) side sensor shows the data trend of almost straight line with the output of 4500 units. Back left (BL) side sensor gives trend same as sensor of back right-side coinciding with back right-side sensor graph curve, giving the minimal deviation from the its reading. While front right (FR) side sensor makes more declining slope with increasing mass in comparison to the raw sensor reading. Finally, the sensor kept in front left (FL) side has a steep slope with decreasing trend as the mass is increased ranging from approximate 3400 to 1700 units.

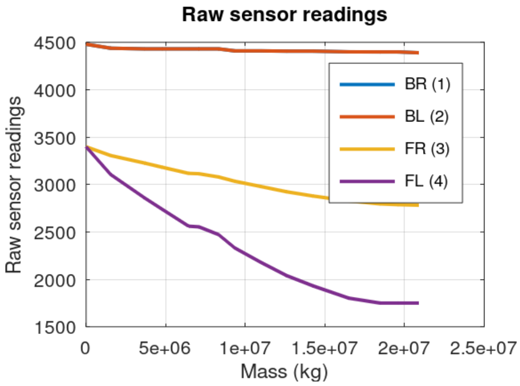

Figure 3-15: Raw sensor data

3.4.2 Angular displacement (theta) Vs Mass

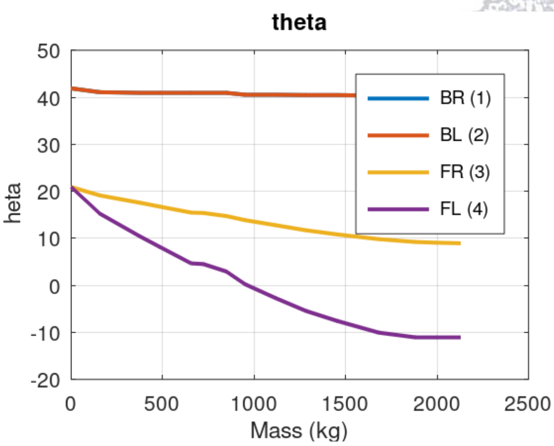

Figure 3-16: Angular displacement by sensor arm

Considering the sensor arm from back right (BR) side, angular displacement remains almost constant making angle of 40°. Sensor arm in back left (BL) side has its curve coincided with the BR sensor and has remained nearly constant for the significant change in the mass. Front side (FR) sensor arm shows nature of slight declination, giving out the pattern of decreasing angular displacement, reaching 9° when the mass is increased to 2300. Sensor arm in front left (FL) side gives great slope with decreasing trend, signifying the change of angular displacement from 20° to -10° when the mass increased from 0 to 2300 kg.

3.4.3 Spring displacements Vs Mass

In front left (FL) side spring displacement shows great increment in first 10 kg mass and remained almost constant of 3 cm even for the significant increase in the mass. The curve representing of spring in front right (FR) has shown the nature which is almost coinciding with the perspective FL side spring. Back right (BR) spring has shown the linearity relationship between spring displacement and mass, reaching maximum 20 cm. On the other hand, the spring located in back left (BL) side shows the greatest slope in which signifies that the even the small change in the mass results in the large and significant displacement in the spring.

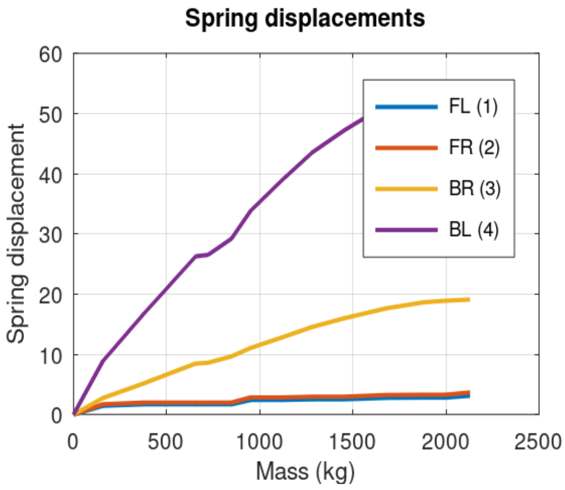

Figure 3-17: Spring displacement

3.5 Testing and validation

After calibrating the sensor, we need to find out the spring constant of the truck leaf spring since the spring constant was unknown to us and to begin the calculation, we used the known weight to find it out. We used water and people as known weight for the experiment. As the springs of the trucks were worn out, we had to carry out some iterations to find out the spring constant. The spring constants were determined to be 2.5e5 N/m for the spring of the front two wheels and 3.7e5 N/m and 1.45e5 N/m for the back two wheels. After the spring constant was determined we could then use the spring constant and the sensor output to estimate the weight of the payload.

The Table *3-1* gives data of the experiment where sensor reading is used to calculate the weight of truck sensed by each sensor.

Table 3-1: Overall payload representation by the sensor on different loading conditions

S. N	Load (KG)	S1	S2	S3	S4	Overall	Error	Remarks
1	100	18	19	29	31	97	3	Loads were placed in back seat and front seat of the vehicle. Loads were targeted in towards the center of the vehicle but due to space availability back seat was used more.
2	250	45	48	73	78	244	2	
3	500	105	99	139	144	487	3	
4	550	120	110	145	155	530	4	
5	600	120	120	180	178	582	3	

After the spring constant of every four sensors are known to us, different known loadings were put in the cargo bed and the spring displacement of each leaf spring were noted. By multiplying the displacement and spring constant, we get the estimated mass or weight of different loading and can be compared for the validation of accuracy of the sensor.

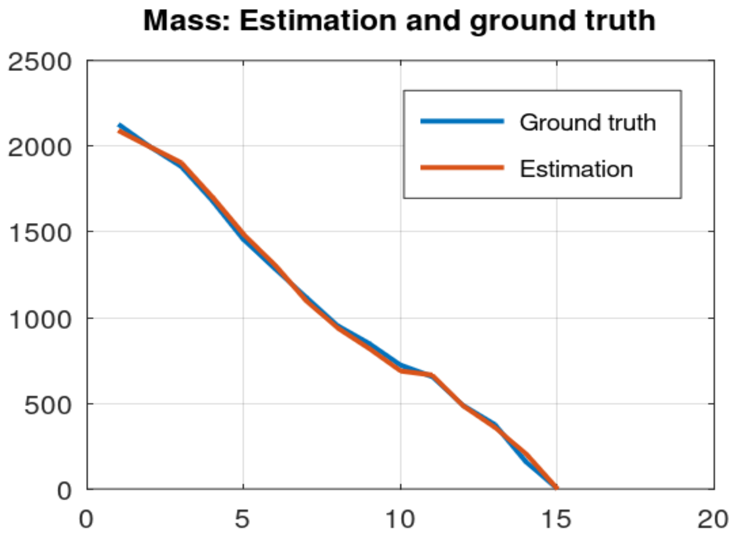

Figure 3-18: Actual Vs Estimated mass

The Figure *3-18* shows the relationship between the ground truth value of mass and the estimated mass, which is obtained with the help of known spring constant and its displacements. We find out the deviation from the ground valued and estimated value is found to be very small i.e., almost negligible. The graph also represents the linear relationship between the angular displacement and the mass.

3.6 Changes incorporated after demonstration

During the project demonstration some practical issues during usage of the weighing sensor system were discussed and the list and detail is mentioned below.

3.6.1 Tare feature to be enabled in the HMI

Previously to stop the vehicle driver from tampering the load of the truck, the tare feature was not provided in the HMI. But, after the demonstration, tare feature was introduced to make the demonstration process more convenient.

3.6.2 Recalibration of the sensors to improve the accuracy

In the first demonstration the error margin observed during random human weight testing as 3-5 percent. After, expert discussion more calibration data was obtained. After recalibration and reduction of backlash error, the error margin was observed less than 2 percent which was agreed to be acceptable in case of larger loads associated to the testing conditions.

3.6.3 Scope to improve the effectiveness of the system

To increase the effectiveness of the system and to enable the ability to monitor truck weight data in real time a Wi-Fi module can be integrated into the ARM Cortex-M3 microprocessor in our project. The HX711 amplifier and the ESP8266 or ESP32 can be integrated into a Wi-Fi module to capture precise weight measurements, and wirelessly transmit them using Wi-Fi. By continuously logging weight information to a remote server, the monitoring team can easily analyze and make decisions based on the data. Whenever the truck's weight exceeds predetermined safety thresholds, real-time data transmission allows real-time alerts to be generated, preventing overloading and potential hazards. The Wi-Fi-enabled alerting system provides reliable and instantaneous data communication that enhances the operational safety and efficiency of truck fleets. It enables remote monitoring, which is crucial for maintaining regulatory compliance and optimizing load management. Through the integration of this technology, weight monitoring accuracy is not only improved, but responsible personnel are also readily able to review and act on this information, contributing significantly to our transportation operations' safety and efficiency.

3.6.4 Possibility of commercial application

The truck overload measurement system created using load gauges has intriguing commercial applications. The sensor system's design and program are easily available and may be shared with technicians and companies interested in creating comparable systems for commercialization. The manual option extends the system's adaptability by allowing for flexible operation in various circumstances. However, the key problem is to scale manufacturing to meet demand. Mass production is a substantial challenge because the controller needs are specific to this application. Despite this issue, with the right resources and knowledge, the system has the potential to be widely adopted in the transportation sector, providing an effective solution for reducing truck overloading and maintaining road safety.

3.7 Design Considerations of the system for future installations

The project necessitates a detailed examination of the design and specifications of the components for future installations. The primary components of the sensor set include the Axle Load Sensor for Leaf Spring Suspension, the Sensor Interface (Modbus), the Control Unit with Touch Screen Display, and various fittings, wiring, and assemblage mechanisms for installation. The development of these components as a system can be approached through two primary methodologies: Integration with vehicle and Stand-alone Approach.

3.7.1 Integration with Vehicle

This approach involves customizing the sensor components for each type of vehicle, ensuring compatibility with specific vehicle protocols and standards. This approach focuses on the following aspects:

- **Vehicle-Specific Protocols and Standards**: Each vehicle manufacturer, such as TATA and Eicher, has unique communication protocols and operational standards. The weighing sensor system must be designed to integrate seamlessly with these specific requirements.
- **Custom Axle Load Sensor**: The axle load sensor needs to be precisely calibrated to the specific vehicle’s suspension system, ensuring accurate weight measurements. For instance, the sensor should be tailored to fit the leaf spring suspension of the TATA Truck used in this project.
- **Cutomized Control Unit**: The control unit should be designed to interface efficiently with the vehicle’s existing electronic systems, ensuring smooth data exchange and reliable operation. Customizing the control unit for each vehicle type enhances the accuracy and functionality of the system.
- **HMI Unit Customization**: The Human-Machine Interface (HMI) must be user-friendly and designed to integrate seamlessly with the vehicle’s dashboard, providing clear and intuitive feedback to the driver. Customizing the HMI for each vehicle ensures better usability and integration.
- **Sensor Interface and Installation Mechanisms**: The sensor interface should be tailored to facilitate efficient communication between the sensor and control unit. The installation mechanisms, including fittings and wiring, should be customized to the specific vehicle’s design, ensuring a secure and reliable setup.

This vehicle-specific approach ensures that the weighing sensor system is finely tuned for each vehicle type, providing maximum efficiency and accuracy.

3.7.2 Stand-alone Approach

The Stand-alone Approach aims to develop a universal weighing sensor system for trucks and buses that is compatible with various types of vehicles. This method emphasizes mass production and cost efficiency. Key considerations include:

- **Universal Compatibility**: The sensor set must be designed to work with a wide range of vehicles, irrespective of manufacturer-specific protocols. This requires a flexible design capable of interfacing with different vehicle systems.
- **Mass Production Benefits**: Standardizing the design allows for mass production, significantly reducing costs. This also enables sharing of Research and Development (R&D) expenses across a broader production base.
- **Compact Integrated Controller**: Developing a more compact form of the control unit, which combines the Modbus, Controller, and HMI into a single unit within the HMI, streamlines installation and reduces space requirements.
- **Versatile Axle Load Sensor**: The axle load sensor should be designed to fit various suspension types, including leaf spring suspensions, enhancing its versatility across different vehicles.
- **Universal Control Unit**: The control unit must be designed to interface with a variety of vehicle electronic systems, ensuring reliable performance across different models. This may involve developing adaptable communication protocols.
- **Flexible HMI Design**: The HMI unit should offer a customizable interface that can be tailored to different vehicle dashboards while maintaining ease of use and clear driver feedback.
- **Standardized Sensor Interface and Installation Mechanisms**: The sensor interface should be standardized to facilitate easy integration with the control unit, and the installation mechanisms should be designed to fit a range of vehicle designs, ensuring secure and efficient installation.

This approach focuses on creating a versatile, cost-effective solution that can be easily adapted to various vehicle types, making it ideal for large-scale implementation.

Both approaches offer distinct advantages for developing and implementing weighing sensor systems in buses and trucks. The vehicle-specific method ensures optimized performance regarding individual vehicle types, while the stand-alone approach emphasizes cost efficiency and universal compatibility. By considering the design and specifications of the sensor set components—Axle Load Sensor for Leaf Spring Suspension, Sensor Interface (Modbus), Control Unit with Touch Screen Display, and various fittings, wiring, and assemblage mechanisms—future installations can be developed to meet the diverse needs of the transportation industry, enhancing safety and operational efficiency across various vehicle platforms.

3.8 Cost and Expenses of the Project

Total expenses of the project is shown in the Table 3-2.

Table 3-2: Budget and Expenses

S.N.	Components	Estimated Price (NRs.)	QTY	Amount (NRs.)
1.	Axle load Sensor for Leaf spring suspension	50,000	5	2,50,000
2.	Sensor Interface	1,97,000	1	1,75,000
3.	Control Unit	1,40,000	1	2,30,000
5.	Wireless module	25,000	1	25,000
Total Quotated Amount				6,80,000
VAT				88,400
Grand Total				7,68,400

CHAPTER FOUR: CONCLUSION & RECOMMENDATION

4.1 Conclusion

During the conduction of this assignment, the researchers installed weighing sensor in a test vehicle with an aim of increasing the road safety of the vehicle. For the completion of the project, the researchers developed a standard design for the installation of weighing sensors which would sense the weight of the vehicle and display the output accordingly and notify the drivers. The researchers further fabricated a hardware based on the design and installed in a test vehicle developing a working prototype as a result. The installed system was first calibrated in series of water filling and emptying experiment. The change in the sensor reading were noted and calibrated as per the change in the mass of the water. For testing purpose, the group of people with their known weight were placed on the cargo bed and made them to get off in turn wise. This system worked properly and displayed the weight carried by the vehicle on the display unit, only with the deviation of 2 to 3 units. Due to this negligible deviation, the project has turned to be more effective and able to fulfill the project intended objectives. Thus, the researchers recommend the use of this system as a baseline for the future innovation in this field of studies.

A significant portion of the vehicle accidents occurring in Nepal are caused by the overloading of vehicles. The use of this system enables the drivers to determine the load they can carry in the vehicle which in turn increases the safety and life of the vehicle, along with road or physical properties near the roadside. This can significantly reduce the chances of vehicle accidents occurring due to overloading. The installation of load sensors on vehicle can help in ensuring compliance with legal weight regulations, preventing overloading and associated penalties. The provision of installing the load sensor can boost the fuel efficiency through load monitoring that ultimately lowering carbon emission.

4.2 Recommendation

While going through this project, we have encountered many problems and challenges caused by various factors like human, technical and geographical site terrain. For the best result in conducting sensor calibration and testing, following are the recommendations that are mentioned by our experts and team members:

- The geographical terrain is supposed to be plain flat but the area where experiment was conducted is slightly uneven, making difficult in calibration and testing. So having the plain flat will be give more precise data in sensor reading and if possible, it is preferred.
- The test vehicle has already worn-out leaf springs resulting in uneven sensor reading caused by less sensitiveness on long use. Having provision of new leaf spring would be better in making correct analysis while calibrating and testing the sensor.
- The sensor calibration and testing were mainly done in static condition in this project, and has produced better result with negligible deviation. But it does not provide results as effective as in the static case when performing experiment in the dynamic condition due to backlash in sensor linkages. Therefore, dynamic weight calibration and estimation can be the further works taking this project as reference.
- The sensor linkages' design was affected by the available vehicle space while conducting this experiment, giving different length and orientation of sensor arm and

associated linkages. It would be better if the provided test truck has space for sensor installation so that the linkage arrangement and orientation would be same, giving more precise output.

- The trucks used in Nepal does not uses only leaf springs for its suspension. Many suspensions system like pneumatic, hydraulic are also used in the vehicle and truck which also needed to be included for the proper execution of the objective of this project.
- This project has set up the foundation to formulate the provision of weight sensor in vehicle but it is not sufficient to execute the weight sensor provision and installation based on it. So, more experiments are needed to be done to have a proper and refined data and information regarding the weighing sensor.

CHAPTER FIVE: REFERENCES

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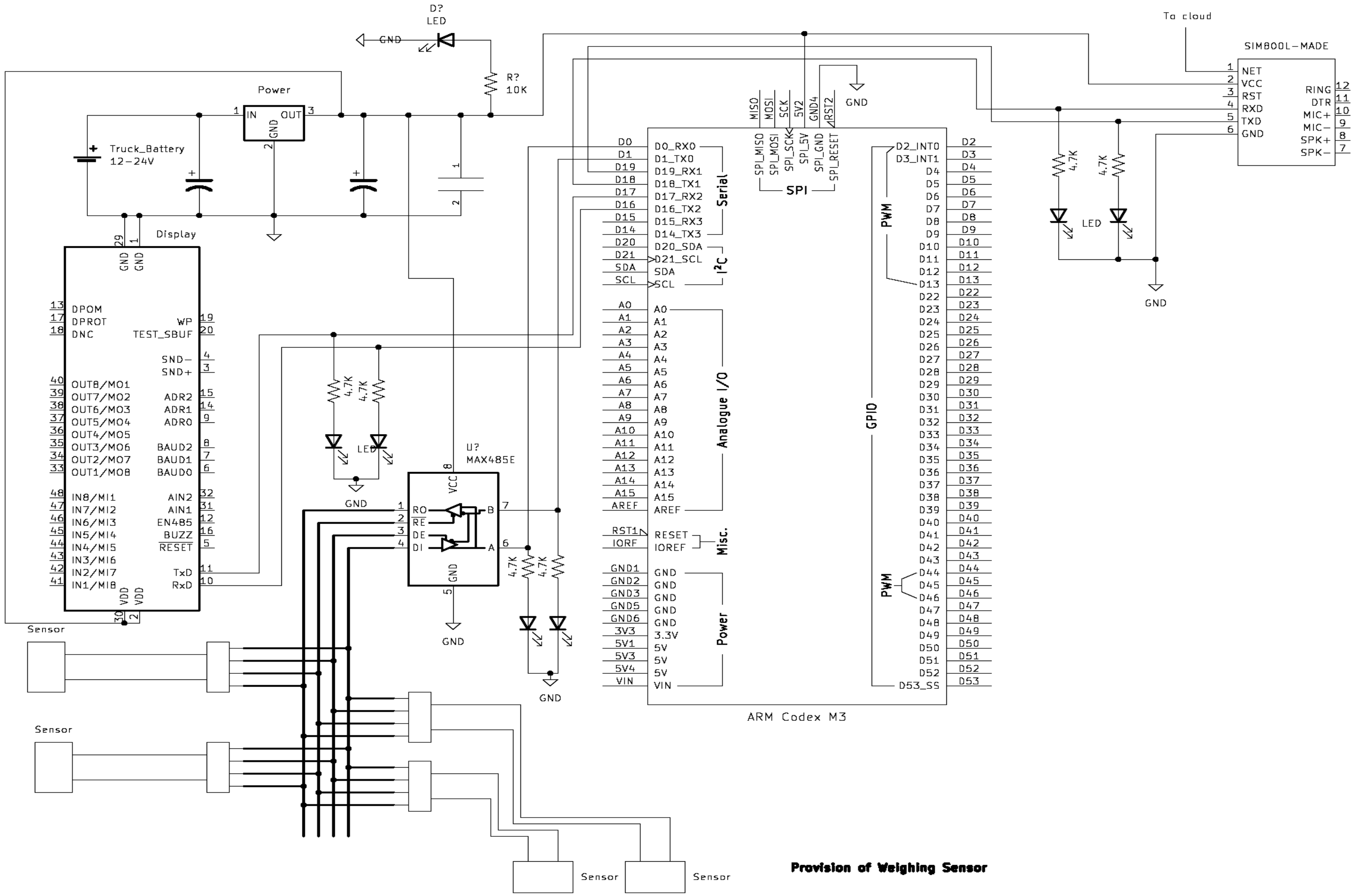
Annex I



Provision of Weighing Sensor

Annex II

Experimental data for sensor calibration

Table 5-1: Results for tuning 1

Tuning Data 1				
Known Mass (Kg)	**Sensor 1**	**Sensor 2**	**Sensor 3**	**Sensor 4**
2233.8	3713	4253	3024	2043
2034.2	3713	4253	3023	2042
1917.7	3713	4253	3021	2042
1790.5	3713	4253	3021	2042
1633.8	3713	4253	3027	2042
1556.2	3713	4253	3032	2052
1403.5	3713	4253	3055	2144
1277.6	3714	4253	3089	2231
1108.9	3729	4253	3143	2385
988.3	3740	4253	3183	2498
889.2	3740	4253	3218	2586
763.3	3790	4253	3269	2735
642.8	3804	4253	3304	2834
466	3833	4253	3397	3102
345.5	3843	4253	3441	3224
0	3902	4253	3576	3584

Table 5-2: Results for tuning 2

Tuning Data 2				
Known Mass (Kg)	**Sensor 1**	**Sensor 2**	**Sensor 3**	**Sensor 4**
2128	2782	1750	4390	3508
1998	2788	1750	4399	3508
1882	2796	1750	4399	3508
1681	2827	1802	4400	3508
1453	2879	1931	4407	3508
1283	2924	2040	4407	3508
1117	2980	2181	4410	3508
951	3035	2332	4410	3508
848	3080	2472	4431	3563
722	3114	2554	4431	3562
656	3118	2561	4431	3562
486	3183	2740	4431	3571
376	3226	2857	4431	3582
157	3306	3106	4438	3630
0	3398	3398	4480	3754

Table 5-3: Results for tuning 3

Tuning Data 3				
Known Mass (Kg)	**Sensor 1**	**Sensor 2**	**Sensor 3**	**Sensor 4**
2114	2770	1738	4378	3496
1984	2776	1738	4387	3496
1868	2784	1738	4387	3496
1667	2815	1790	4388	3496
1439	2867	1919	4395	3496
1269	2912	2028	4395	3496
1103	2968	2169	4398	3496
937	3023	2320	4398	3496
834	3068	2460	4419	3551
708	3102	2542	4419	3550
642	3106	2549	4419	3550

472	3171	2728	4419	3559
362	3214	2845	4419	3570
143	3294	3094	4426	3618
0	3386	3386	4468	3742

Annex III

MATLAB codes for calibration and testing:

1. data_collection

```
clc
clear
close all

sensor1 = [2782, 2788, 2796, 2827, 2879, 2924, 2980, 3035, 3080, 3114, 3118, 3183, 3226,
3306, 3398];
sensor2 = [1750, 1750, 1750, 1802, 1931, 2040, 2181, 2332, 2472, 2554, 2561, 2740, 2857,
3106, 3398];
sensor3 = 4640 - [250, 241, 241, 240, 233, 233, 230, 230, 209, 209, 209, 209, 209, 202, 160];
sensor4 = 4640 - [1132, 1132, 1132, 1132, 1132, 1132, 1132, 1132, 1077, 1078, 1078, 1069,
1058, 1010, 886];
mass = [2128,1998,1882,1681,1453,1283,1117,951,848,722,656,486,376,157,0];

x = mass;

figure;
plot(x, sensor1, 'LineWidth', 2);
hold on;
plot(x, sensor2, 'LineWidth', 2);
plot(x, sensor3, 'LineWidth', 2);
plot(x, sensor4, 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
grid on;
title("First data");

clc
clear

sensor1 = 4640 - [927, 927, 927, 927, 927, 927, 927, 926, 911, 900, 900, 850, 836, 807, 797,
738];
sensor2 = 4640 - [387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387,
387];
sensor3 = [3024, 3023, 3021, 3021, 3027, 3032, 3055, 3089, 3143, 3183, 3218, 3269, 3304,
3397, 3441, 3576];
sensor4 = [2043, 2042, 2042, 2042, 2042, 2052, 2144, 2231, 2385, 2498, 2586, 2735, 2834,
3102, 3224, 3584];
mass = [2233.8, 2034.2, 1917.7, 1790.5, 1633.8, 1556.2, 1403.5, 1277.6, 1108.9, 988.3,
889.2, 763.3, 642.8, 466, 345.5, 0];

figure;
plot(mass, sensor1, 'LineWidth', 2);
hold on;
```

```
plot(mass, sensor2, 'LineWidth', 2);
plot(mass, sensor3, 'LineWidth', 2);
plot(mass, sensor4, 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
grid on;
title("Second data");
```

2. get_front_h

```
function h = get_front_h(x, y, z, theta)
  a = 1;
  b = - 2 * x * sin(theta);
  c = x.^2 - y.^2 + z.^2 + 2 * x * z * cos(theta);
  root_term = sqrt(b.^2 - 4 * a * c);

  if(isreal(root_term))
    if((-b + root_term) > 0)
      h = (-b + root_term) / (2 * a);
    else
      h = (-b - root_term) / (2 * a);
    end
  end
end
```

3. get_rear_h

```
function h = get_rear_h(x, y, z, theta)
  a = 1;
  b = - 2 * x * sin(theta);
  c = x.^2 - y.^2 + z.^2 - 2 * x * z * cos(theta);
  root_term = sqrt(b.^2 - 4 * a * c);

  if(isreal(root_term))
    if((-b + root_term) > 0)
      h = (-b + root_term) / (2 * a);
    else
      h = (-b - root_term) / (2 * a);
    end
  end
end
```

4. predict

```
function mass = predict(a, b, c, d, k)
  mass = k(1) .* a + k(2) .* b + k(3) .* c + k(4) .* d;
end
```

5. regression (calibration)

```
clc
clear
close all
format long


%{
   (1,a) ___\/____ (2,b)
        || FRONT ||
        ||       ||
        ||       ||
        ||       ||
   (4,d)||_______||(3,c)
           REAR
%}

% Sensor geometry (mm)
c_x = 98; c_y = 310; c_z = 130;
d_x = 98; d_y = 312; d_z = 130;
b_x = 110; b_y = 440; b_z = 118;
a_x = 110; a_y = 414; a_z = 24;
g = 9810; % mm/s^2

% Sample data
a = 4640 - [927, 927, 927, 927, 927, 927, 927, 926, 911, 900, 900, 850, 836, 807, 797, 738];
b = 4640 - [387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387];
c = [3024, 3023, 3021, 3021, 3027, 3032, 3055, 3089, 3143, 3183, 3218, 3269, 3304, 3397,
3441, 3576];
d = [2043, 2042, 2042, 2042, 2042, 2052, 2144, 2231, 2385, 2498, 2586, 2735, 2834, 3102,
3224, 3584];
f = [2233.8, 2034.2, 1917.7, 1790.5, 1633.8, 1556.2, 1403.5, 1277.6, 1108.9, 988.3, 889.2,
763.3, 642.8, 466, 345.5, 0]*g;
a = a(6:16);
b = b(6:16);
c = c(6:16);
d = d(6:16);
f = f(6:16);

% Sensor reading to theta
theta_factor = deg2rad(90/4640);
a_theta = a * theta_factor - pi/4;
b_theta = b * theta_factor - pi/4;
c_theta = c * theta_factor - pi/4;
d_theta = d * theta_factor - pi/4;
```

```
% Initial h
a_h0 = get_front_h(a_x, a_y, a_z, a_theta(length(a)));
b_h0 = get_front_h(b_x, b_y, b_z, b_theta(length(b)));
c_h0 = get_rear_h(c_x, c_y, c_z, c_theta(length(c)));
d_h0 = get_rear_h(d_x, d_y, d_z, d_theta(length(d)));

% theta to displacement
a_dx = a_h0 - get_front_h(a_x, a_y, a_z, a_theta);
b_dx = b_h0 - get_front_h(b_x, b_y, b_z, b_theta);
c_dx = c_h0 - get_rear_h(c_x, c_y, c_z, c_theta);
d_dx = d_h0 - get_rear_h(d_x, d_y, d_z, d_theta);

% Least squares fit
% f = k1 * x1 + k2 * x2 + k3 * x3 + k4 * x4
X = [a_dx', b_dx', c_dx', d_dx'];
k = X \ f'

% Predictions
f_hat = predict(a_dx, b_dx, c_dx, d_dx, k);

figure;
plot(f, a, 'LineWidth', 2);
hold on;
plot(f, b, 'LineWidth', 2);
plot(f, c, 'LineWidth', 2);
plot(f, d, 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
title("Raw sensor readings");
xlabel("Mass (kg)");
ylabel("Raw sensor readings");
grid on;

figure;
plot(f / g, rad2deg(a_theta), 'LineWidth', 2);
hold on;
plot(f / g, rad2deg(b_theta), 'LineWidth', 2);
plot(f / g, rad2deg(c_theta), 'LineWidth', 2);
plot(f / g, rad2deg(d_theta), 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
title("theta");
xlabel("Mass (kg)");
ylabel("\theta");
grid on;
```

```
figure;
plot(f / g, a_dx, 'LineWidth', 2);
hold on;
plot(f / g, b_dx, 'LineWidth', 2);
plot(f / g, c_dx, 'LineWidth', 2);
plot(f / g, d_dx, 'LineWidth', 2);
legend('FL (1)','FR (2)','BR (3)','BL (4)');
title("Spring displacements");
xlabel("Mass (kg)");
ylabel("Spring displacement");
grid on;

figure;
plot(f / g , 'LineWidth', 2);
hold on;
plot(f_hat / g, 'LineWidth', 2);
title("Mass: Estimation and ground truth");
legend('Ground truth', 'Estimation');
grid on;
```

6. test_gain

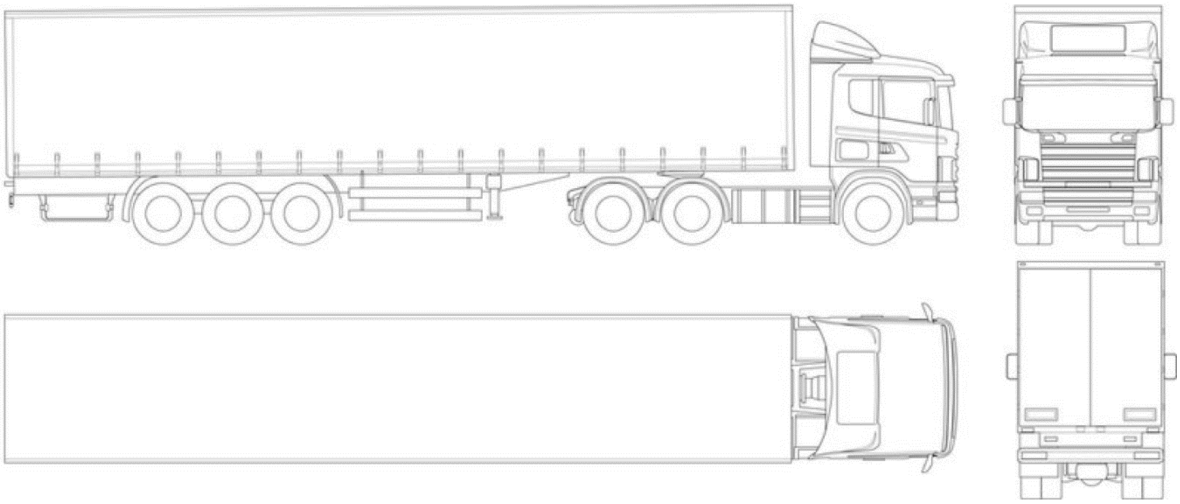
```
clc
clear
close all
format long

%{
   (1,a) ___\/____ (2,b)
         || FRONT ||
         ||       ||
         ||       ||
         ||       ||
   (4,d)||_______||(3,c)
            REAR
%}

% Manually tuned spring constants
k = [2.5e5, 2.5e5, 3.7e5, 1.45e5];

% Sensor geometry (mm)
c_x = 98; c_y = 310; c_z = 130;
d_x = 98; d_y = 312; d_z = 130;
b_x = 110; b_y = 440; b_z = 118;
a_x = 110; a_y = 414; a_z = 24;
```

```
g = 9810; % mm/s^2

% Sample data
a = 4640 - [927, 927, 927, 927, 927, 927, 927, 926, 911, 900, 900, 850, 836, 807, 797, 738];
b = 4640 - [387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387, 387];
c = [3024, 3023, 3021, 3021, 3027, 3032, 3055, 3089, 3143, 3183, 3218, 3269, 3304, 3397,
3441, 3576];
d = [2043, 2042, 2042, 2042, 2042, 2052, 2144, 2231, 2385, 2498, 2586, 2735, 2834, 3102,
3224, 3584];
f = [2233.8, 2034.2, 1917.7, 1790.5, 1633.8, 1556.2, 1403.5, 1277.6, 1108.9, 988.3, 889.2,
763.3, 642.8, 466, 345.5, 0]* g;
a = a(6:16);
b = b(6:16);
c = c(6:16);
d = d(6:16);
f = f(6:16);

% Sensor reading to theta
theta_factor = deg2rad(90/4640);
a_theta = a * theta_factor - pi/4;
b_theta = b * theta_factor - pi/4;
c_theta = c * theta_factor - pi/4;
d_theta = d * theta_factor - pi/4;

% Initial h
a_h0 = get_front_h(a_x, a_y, a_z, a_theta(length(a)));
b_h0 = get_front_h(b_x, b_y, b_z, b_theta(length(b)));
c_h0 = get_rear_h(c_x, c_y, c_z, c_theta(length(c)));
d_h0 = get_rear_h(d_x, d_y, d_z, d_theta(length(d)));

% theta to displacement
a_dx = a_h0 - get_front_h(a_x, a_y, a_z, a_theta);
b_dx = b_h0 - get_front_h(b_x, b_y, b_z, b_theta);
c_dx = c_h0 - get_rear_h(c_x, c_y, c_z, c_theta);
d_dx = d_h0 - get_rear_h(d_x, d_y, d_z, d_theta);

% Predictions
f_hat = predict(a_dx, b_dx, c_dx, d_dx, k);

figure;
plot(f, a, 'LineWidth', 2);
hold on;
plot(f, b, 'LineWidth', 2);
plot(f, c, 'LineWidth', 2);
```

```
plot(f, d, 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
title("Raw sensor readings");
xlabel("Mass (kg)");
ylabel("Raw sensor readings");
grid on;

figure;
plot(f / g, rad2deg(a_theta), 'LineWidth', 2);
hold on;
plot(f / g, rad2deg(b_theta), 'LineWidth', 2);
plot(f / g, rad2deg(c_theta), 'LineWidth', 2);
plot(f / g, rad2deg(d_theta), 'LineWidth', 2);
legend('BR (1)','BL (2)','FR (3)','FL (4)');
title("theta");
xlabel("Mass (kg)");
ylabel("\theta");
grid on;

figure;
plot(f / g, a_dx, 'LineWidth', 2);
hold on;
plot(f / g, b_dx, 'LineWidth', 2);
plot(f / g, c_dx, 'LineWidth', 2);
plot(f / g, d_dx, 'LineWidth', 2);
legend('FL (1)','FR (2)','BR (3)','BL (4)');
title("Spring displacements");
xlabel("Mass (kg)");
ylabel("Spring displacement");
grid on;

figure;
plot(f / g , 'LineWidth', 2);
hold on;
plot(f_hat / g, 'LineWidth', 2);
title("Mass: Estimation and ground truth");
legend('Ground truth', 'Estimation');
grid on;
```

Annex IV

Schematic diagram of truck



Different views of truck (solid modeling)

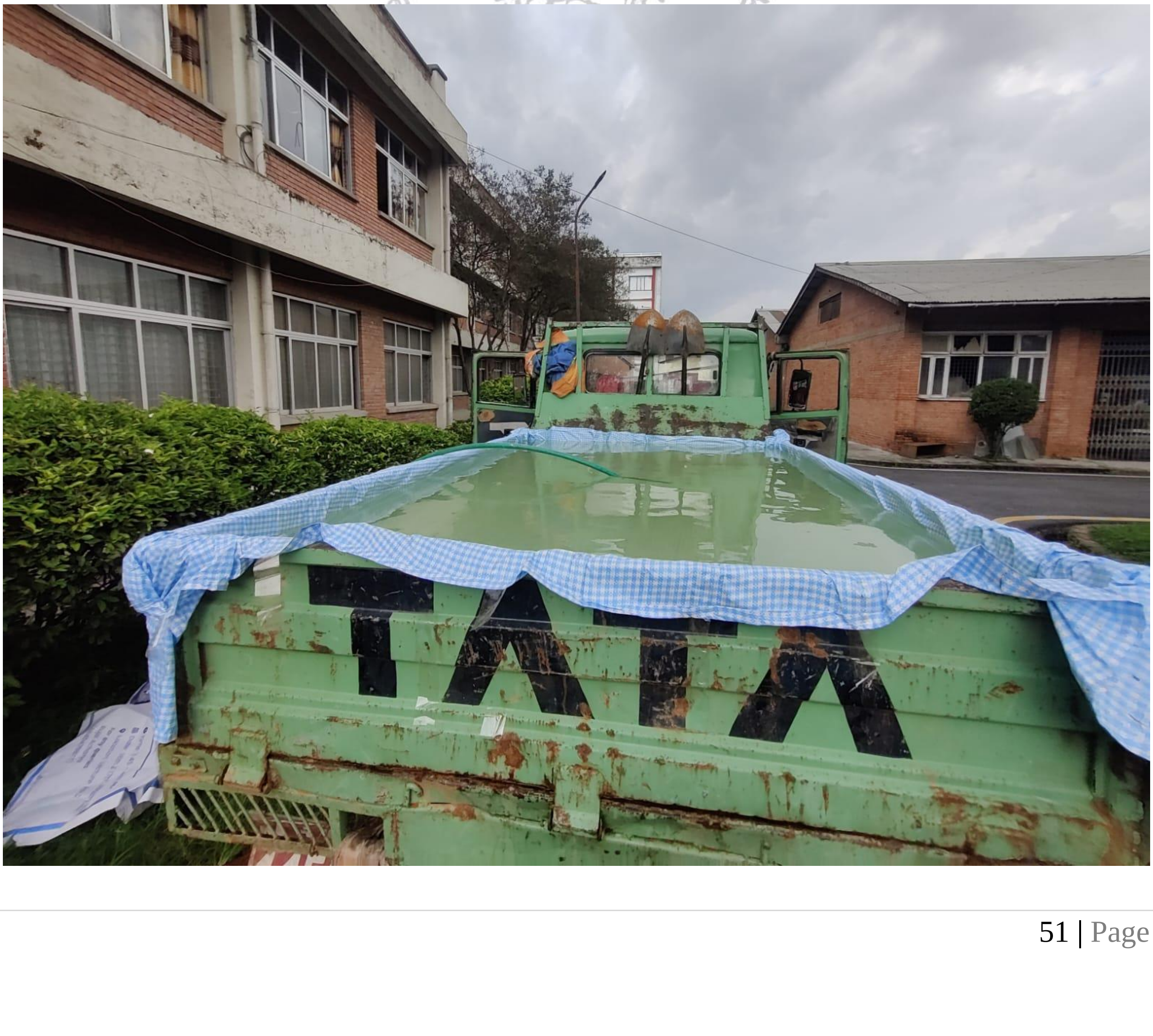
Annex V

1. Photographs during sensor calibration using calibrated live load (distributed point load)

2. During demonstration of Weighing sensor

3. Loading the test vehicle with rated payload (water as payload) for uniform loading

3. Pictures showing vehicle with 2.5 tons of payload



4. Photograph during draft presentation

5. Photographs during the sensor testing and validation

6. Dashboard displaying varying measured payloads

a. 60kg

b. 163kg

c. 230 kg

d. 305 kg

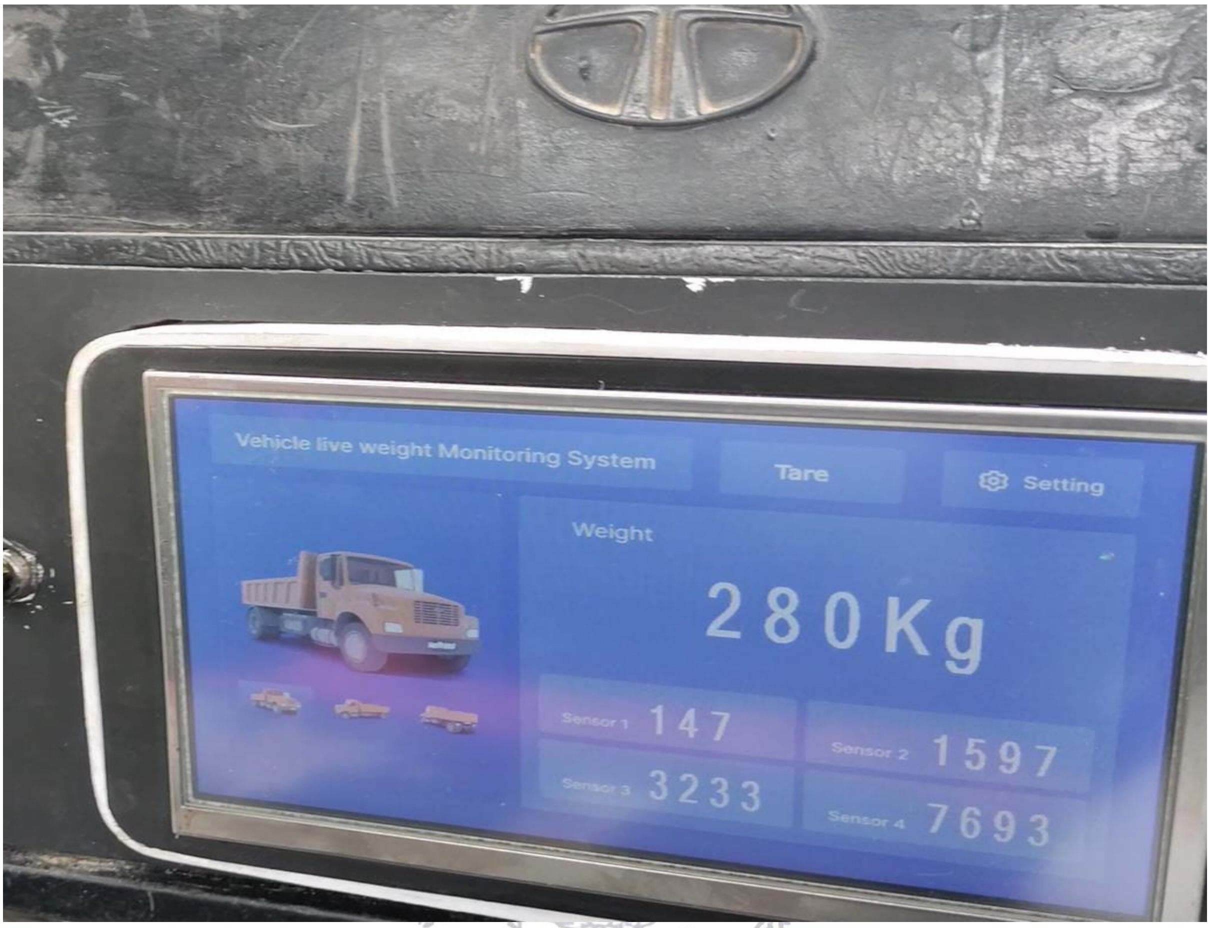
e. 364 kg

f. 450 kg

g. 555 kg

h. 436 kg

i. 280 kg



j. 183 kg

k. 54 kg


Vehicle live weight Monitoring System
Tare
Setting
Weight
54Kg
Sensor 1 0
Sensor 2 1638
Sensor 3 349
Sensor 4 0

l. 7 kg


7Kg

ANNEX VI: COMMENT MATRIX

S.N.	Comments	Remarks
1.	Consider adding literature review in the draft report	Literature review section has been added in the section (2.1) (Pages: 5-9)
2.	Include the specifications developed and the detailed design for the procured goods and components in section 2.4.1	The specifications of the procured goods and components are mentioned in the section (2.4.1)(Page 11)
3.	Include the cost analysis of the project	Expenses and cost of the project is mentioned in the section (3.8)(Page 29)
4.	The pictures in the Annex V requires explanation	Schematic diagram of the test vehicle is now changed to match with the actual test vehicle that has been utilized in the report. Changes made are in the Annex V (Pages: 50-53)
5.	Please consider addressing point no. 4 of the scope in the research agreement which states to develop the design and specifications of the system for future installations	Design Considerations of the system for future installations is mentioned briefly in section (3.7) (Pages: 27, 28)