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Development of an Arduino-Based Truck Load Detection System for Bridge Safety Monitoring

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Abstract: The safety of bridge structures is very important to consider, especially in withstanding the weight of passing trucks. Overloading can cause structural damage that can potentially jeopardize the safety of bridge users. Therefore, a truck load weight detection system is needed that is able to monitor the load in real-time and provide early warning in the event of overloading. This research aims to design and implement an Arduino-based truck load weight detection system installed on the bridge. This system uses a load sensor (load cell) to measure the weight of passing vehicles, where the weight data is then processed by an Arduino arduiuno. The system is equipped with a wireless communication module that allows weight data to be sent directly to the control center or bridge operator. The results of system testing show that this system is able to detect the weight of truck loads with a good level of accuracy. With this system, it is expected to improve bridge safety and provide accurate information related to the distribution of loads passing over the bridge.

Keywords: Arduino; Load Cell Sensor; Truck Load Detection; Bridge Safety Monitoring; Wireless Communication System

INTRODUCTION

In the era of modern technological development, the use of computers in various fields is familiar. Computer technology is evolving so rapidly in everything from simple jobs to large, complex projects. Now there are many applications that use computer-based information systems. According to (Ridwan et al., 2021) "The system is the basis of movement in all activities, the existence of a system in all fields, when it is needed, without the concept of the system of activities or work will run uncontrollably".

According to (Wijoyo, 2021)"A system is a group of elements that interact with each other to achieve a certain goal". This system is generally used to ensure that the load transported by the truck does not exceed the maximum safe limit for the bridge (Khristianto, 2022). The bridge is an essential infrastructure in transportation used to connect roads and facilitate the movement of vehicles, including trucks that carry a heavy load. Here, the author made a replica of the bridge with a scale of 1:1600, which means that each part of the replica is 1600 times smaller than the same part of the original bridge. For example, if a replica weighs 2 kg, then the actual weight on the bridge is 3200 kg (2 kg x 1600).

A truck is a large vehicle for transporting goods, also known as a freight car. In the small form, the freight car is referred to as a pick-up, while the larger form with 3 axes, 1 in the front, and a tandem in the rear is referred to as a truck tronton, while those used for transporting containers in the form of stickers are referred to as a truck trailer. (Vehicle Load Monitoring System Design Using Load Cell Sensor Technology: Journal of Information Technology, Volume 6, No. 2, Mohammad Husni Thamrin University (Sibuea & Saftaji, 2020)

Trucks are often operated with excess loads. Operation of trucks with loads exceeding the permitted capacity can cause serious damage to the bridge, threaten the safety of road users, and require high repair costs. Therefore, it is important to have a truck load weight detection system that can identify trucks with excess loads before crossing bridges. Arduino technology has been widely used in electronic projects and automatic control systems.

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

Arduino offers ease of use, flexibility, and relatively low cost, making it an ideal choice for developing truck load detection systems. Using Arduino, we can integrate sensitive weight sensors and process the data obtained to identify whether the truck's load weight exceeds the permissible limit. Sensitive weights can be easily integrated, and the data obtained can be processed to calculate the truck's load weight.

The inspiration for this research cannot be separated from previous research, one of which is a journal entitled "An Automatic Load Detector Design to Determine the Strength of Pedestrian Bridges Using Load Cell Sensor Based on ArduinoSão Paulo (Kartika Riyanti et al., 2022), explaining the design of an automatic load detection system to determine the strength of the pedestrian bridge. This research uses a load cell, which is controlled by an Arduino, to measure the load that is on the bridge. The main purpose of this study is to detect the maximum load that can be supported by a pedestrian bridge, as well as to provide warnings if the load is borne close to or exceeds the safe limit.

The system designed consists of a Load cell sensor that measures the weight of the load directly, an Arduino as the main controller, and software that manages measurement data and provides real-time alerts. This research focuses on how Load cell sensors can provide accurate data to detect overload and ensure the safety of pedestrian bridge structures.

Meanwhile, the research on the Arduino-based truck load detection system that the author is working on lies in the detected object, the type of bridge, the measurement scale, the detection purpose, and the complexity of the system. The journal Riyanti et al. focused on the detection of pedestrian loads on pedestrian bridges, with a smaller load compared to truck loads, while the authors' research focused on the detection of the weight of trucks passing on bridges with much greater loads. The pedestrian bridge in Riyanto et al.'s study is designed for light loads, while the bridges in the author's research are designed to withstand the weight of heavy vehicles. In addition, the measurement system in the journal measures a load of tens to hundreds of kilograms, while the authors' research requires a sensor with a larger capacity to measure a load of several tons. The purpose of detection in the journal Riyanti et al. is to monitor the strength of the pedestrian bridge and provide warnings if overload occurs, while the author's research focuses on ensuring that trucks do not exceed the capacity of the bridge in order to prevent the risk of damage to the bridge structure and maintain safety, as well as extend the life of the bridge by avoiding overload, and provide warnings if overload occurs. The complexity of the system in the author's research is also higher because it requires more complex data calculation and management related to larger truck loads.

Another journal that is a source of inspiration for the author is a journal entitled "Automatic Bridge Control Using Arduino-Based Ultrasonic Sensors" Works (Pranita, 2023), discussed the bridge automation system using ultrasonic sensors controlled by Arduino. This research aims to improve traffic safety and efficiency on bridges by utilizing automation technology. The system designed in this study uses ultrasonic sensors to detect the presence of vehicles around the bridge. When the sensor detects a vehicle, the Arduino will control the opening or closing of the bridge automatically. The system is also equipped with software to manage bridge operations, including mechanisms to prevent congestion or accidents in the bridge area. The research focuses on how the use of ultrasonic sensors can help create a responsive and efficient bridge control system, with the main goal of improving the safety and comfort of road users crossing the bridge.

Meanwhile, the author's research lies in the type of sensor, the purpose of the system, the type of control, the complexity, and the focus on safety. Jurnal Pranita et al. use ultrasonic sensors to detect the presence of vehicles around the bridge, with the aim of controlling the opening and closing of the bridge automatically to improve safety and smooth traffic, while the author's research uses a Load cell sensor to measure the weight of the truck's load to ensure that vehicles do not exceed the capacity of the bridge and maintain the safety of the road structure. In terms of control, the Pranita et al. system focuses more on bridge access management, while the author's research focuses more on load monitoring. The Pranita et al. system only requires the detection of the presence of vehicles, while the author's research involves precision measurement and processing of load data. The focus of safety in the journal Pranita et al. is on smooth traffic and preventing accidents, while the author's research focuses on protecting bridge structures from damage due to overload.

Another journal that is also an inspiration for the author is from the National Journal of Electrical Engineering, entitled "Sensor Automation Load cell to Overcome Overload VehiclesSão Paulo (Kurnia et al., 2019), explaining that the use of sensors, load cell integrated with Arduino-based automated systems, to detect and prevent overloaded vehicles (Overload). The system is designed to measure the weight of the vehicle in real-time when the vehicle passes the measurement point, with the aim of providing an alert or taking automatic action if the vehicle load exceeds the predetermined limit. This research involves the Load cell, which acts as the main tool for measuring loads, while Arduino is used to process data from sensors and control automated mechanisms such as warning signals or roadblocks. This system aims to improve road and infrastructure safety by preventing overloaded vehicles from crossing bridges or roads that have a certain capacity limit. This research focuses on the

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

measurement accuracy and effectiveness of automated systems in detecting and addressing problems with overloaded vehicles.

Meanwhile, the research on the Arduino-based truck load detection system that the author is working on lies in the objectives, actions after detection, the scale of the vehicle, and the focus of the infrastructure. Jurnal Kurnia et al., aims to detect vehicle overload in general in various locations such as highways, with a system that provides automatic warnings or actions if the load exceeds the safe limit, while the author's research focuses more on detecting the weight of trucks crossing bridges to ensure that they do not exceed the capacity of the bridge and maintain the safety of the bridge structure. The Kurnia et al. system applies to various types of vehicles, while the author's research is more specific to heavy trucks. The author's research has a specific focus on bridge protection, while the Kurnia et al. journal covers broader infrastructure protection.

Previous studies have shown some significant differences in technology and the purpose of use. Journal Riyanti et al. in 2022, used a Load cell sensor to measure the load of pedestrians on bridges, focusing on light load detection and providing simple warnings, so the system is relatively simple. Journal Pranita et al. in 2023, use ultrasonic sensors to detect the presence of vehicles and control bridge access automatically, without measuring loads, so that they focus more on access management. Journal Kurnia et al. also uses Load cell sensors to detect vehicle overload in general, with a system that provides automatic warnings or actions, but is not specific to the bridge.

The author's research uses a Load cell sensor to accurately measure the weight of trucks passing on the bridge. The authors' research requires tools that can accurately measure heavy truck loads and manage the data to protect bridges, while previous research has focused more on light loads or vehicle detection without measuring loads in depth. Thus, the authors' research is more complex compared to previous studies because it involves more detailed measurements of heavy loads and structural protection of bridges.

The purpose of this research is to design and implement an Arduino-based truck load detection system that is able to provide weight information accurately and in real-time. With this system, it is hoped that it can help the authorities in monitoring and maintaining the safety and resilience of the bridge. In addition, the results of this study are expected to be a reference for the development of similar systems in the future, especially to reduce the risk of damage to bridge infrastructure due to excessive loads from passing heavy vehicles.

LITERATURE REVIEW

1. Definition of System

A system is a unit consisting of elements or components that interact with each other and are organized to achieve a certain goal (Wijoyo, 2021). The system has the main components in the form of inputs, processes, and outputs. Input is the resource that enters the system, the process is the processing stage, and the output is the result of the process (Ridwan et al., 2021). System characteristics include the presence of components, system boundaries, external environment, interfaces, inputs, outputs, processing processes, and goals. Systems can be classified into abstract and physical systems, natural and artificial systems, deterministic and probabilistic systems, and open and closed systems.

2. Definition of Detector

A detector is a tool or system used to recognize, identify, or measure the presence of an object or a change in certain conditions (Nurlaila et al., 2024). Detectors can be hardware, such as sensors, or software, such as pattern recognition systems. Its function is widely used in the fields of security, industry, and information technology to improve system efficiency and accuracy.

3. Sensor Load Cell

A load cell is a sensor used to measure force or weight by converting mechanical force into an electrical signal through the principle of material deformation and a strain gauge assembled in a Wheatstone bridge (Laili & Bahri, 2022). These sensors are widely used in digital weighing systems because they have a high level of accuracy. The commonly used types are beam bending and single-point types for light to medium loads (Kazuya et al., 2024).

4. HX711 Module

The HX711 is a 24-bit Analog to Digital Converter (ADC) amplifier module specifically designed to read signals from load cells (Handiko, 2022). These modules amplify small signals from sensors and convert them into digital data that can be processed by Arduino. The HX711 works at a voltage of 5V and has two input channels with adjustable gain.

5. Arduino

Arduino Uno is an open-source Arduino platform based on ATmega328P that is used to develop interactive electronic systems. Arduino consists of hardware (board) and software (Arduino IDE) for writing and uploading

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

programs (Arsyad & Kartika, 2021). In addition to Uno, there is the Arduino Mega 2560, which has more pins and memory for large-scale projects, and the Arduino Nano, which is smaller in size and suitable for projects with limited space. Arduino serves as the system control center for reading sensors and controlling actuators (Sunardi et al., 2024).

6. LCD

An LCD (Liquid Crystal Display) is a display device that uses liquid crystals to display text or information (Gunawan & Ardiyansyah, 2023). In this study, a 16x2 LCD was used, which was able to display two lines of text of 16 characters each. LCD serves as an information medium to display weight measurement results (Widharma, 2021).

7. Step-Down (Buck Converter)

A step-down is a circuit of electronics that functions to lower the DC voltage from a higher level to a lower level (Rustandi, 2020). One of the commonly used ICs is the LM2596, which is capable of generating a stable voltage with currents up to 3A. This module maintains the stability of the power supply in the electronic system. "IC LM2596 is an integrated circuit with a function as a step-down DC converter with a current rating of 3A". (Automatic Transfer Switch (ATS) Using Arduino Uno, IoT-Based Relay and Monitoring, Journal of Telecommunication System, Electronics, or Bhayangkara University Surabaya) (Rizal-Alfariski et al., 2022).

8. Buzzer

A buzzer is an electronic component that converts electrical signals into sound (Rachmawati, n.d.). The buzzer works using the electromagnetic or piezoelectric principle and is used as an indicator or alarm when the weight exceeds the specified limit. A buzzer is an electronic component that functions to convert electrical vibrations into sound vibrations. The buzzer has an electromagnetic coil attached to the diaphragm". (Simanjuntak, 2023)

9.Motor Servo

A servo motor is a rotary actuator with a closed feedback control system that allows for precise angle position adjustment (Sunardi et al., 2024). A servo motor is a rotary actuator or a device called a motor, which is designed using a closed-loop feedback control system called a servo (Source, 2020). Servos are controlled using PWM signals from Arduino and generally have a motion range of 0–180°. In this system, a servo motor is used to drive the automatic cross mechanism.

METHOD

Research Stages

This research uses observation methods, laboratory research, literature methods, testing, and analysis of results. Observation is to identify the main problems on the bridge related to the load of passing trucks, as well as to study the need for real-time weight measurement. This stage involves observation in the field or under conditions similar to actual conditions. Laboratory research involves conducting experiments and testing detection systems in the laboratory. At this stage, the components of the system are tested to ensure each element (such as the weight sensor and Arduino) functions correctly before being implemented in the field. The Literature Method is collecting and analyzing data from various relevant literature to strengthen the theoretical basis used, both related to sensors, Arduino, and truck weight detection systems. Testing is testing a system that has been designed using truck load simulations. The data obtained from the weight sensor will be collected to ensure the accuracy and reliability of the system. Result Analysis is analyzing test result data to evaluate the performance of the load detection system, including accuracy, response speed, and consistency of results.

Troubleshooting Methods

The stages to overcome the problems in this study are the calibration and validation of the heavy sensor outlining the stages of sensor calibration to ensure the accuracy of the measurement results in accordance with the standard. This method is important so that the detection system can read the weight of the load with high precision. Data testing and processing is the processing of data from sensors to be displayed in an easy-to-understand format. At this stage, statistical analysis or comparison with reference values is also carried out to test the accuracy of the system.

RESULTS

System implementation is a procedure that is carried out to complete the design of the existing system in the approved design document, test the system, install it, and start the new system that has been created. In the creation of an Arduino-based bridge crossing truck detection system program with maximum weight load setting, overload

* Delima Astuti Rambe, et.all

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

warning is designed using hardware and software that have been tested at the Robotics Lab of the Indonesian Institute of Technology and Business (ITBI) and can function as desired, with the following results:

1. Load cells are used to detect the weight of the load of trucks that want to cross the bridge.
2. The designed servo motor serves as an automatic portal opener.
3. LCD Display is used to display the truck's load weight.
4. A buzzer is used as a warning alarm.
5. Wi-Fi, which functions as a connectivity between a web-based tablet or laptop with a system that has been designed to find out the load data of passing trucks.
6. The design of the software system on the Arduino 32+, which functions to convert the reading results from the above features.

Based on the design results above, for more detailed test results, the overall load detection system for trucks across bridges based on Arduino can be explained as follows.

Hardware Results Display

The following is a view of the results of the hardware that has been designed and implemented. This image shows the entire system that includes key components such as Arduino, sensor modules, and neatly arranged display devices. Each part has been assembled according to the design scheme, with proper connections to ensure the optimal functioning of the meticulous assembly process and trials carried out to ensure that all components work as expected.

Fig 1. Results of the Truck Load Detection System Crossing Bridges

Figure 1 presents a front view of the truck load detection system designed specifically for this bridge. Load sensors attached to the main scale before crossing the bridge transmit data in real-time to the data processing unit. This system is expected to provide early warning if there are vehicles that exceed the allowed tonnage limit, so as to prevent damage to the bridge structure.

System Working Mechanism

The working mechanism of the truck load detection system crossing the bridge starts when the truck stops on the scale, and this is where the Load cell sensor installed under the scale comes into operation. These load cells read the pressure generated by the weight of the truck and convert it into an electrical signal. The signal from the load cell is then forwarded to an Arduino, which is in charge of processing the data into readable truck weight information.

After the Arduino processes the data, the results of the truck's weight measurements will be displayed directly on the LCD screen installed around the scale area. This information is useful for operators or users who want to know the weight of a passing truck directly. In addition to displaying information on the LCD screen, this processed data is also sent to the web server through a connection that has been set up in the system. The data is automatically stored on the server and then displayed in the form of statistics on the web page. On this webpage, users can view daily statistics such as the number of vehicles that pass, the average weight of the vehicle, and the details of each vehicle that passes, including the time and date.

If trucks do not exceed the permissible load limit, the system will work normally. When the truck is on the scale, the load cell sensor measures the truck's weight and sends the data to the Arduino. The Arduino processes the data and compares it to the maximum limit that has been set. If the truck's weight is within safe limits, the information will be displayed on the LCD screen. The system will also send the data to the web server to be stored

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

and displayed in the form of statistics on the web page. And the automatic bar will open, allowing the truck to pass unimpeded, and then close again once the truck has completely passed the scale.

If the weight of the passing truck exceeds the maximum limit that has been set, then the system will automatically give a notification, both on the LCD screen and on the web page, and the buzzer will automatically emit a warning sound. This notification is useful as a warning to operators that passing trucks are carrying excess loads, which can pose a risk to the bridge structure. With this mechanism, the system not only functions as a vehicle weight measuring device, but also as a supervisory tool to keep the load of passing vehicles within safe limits.

Website Results Display

The following is a website displaying detailed data about the weight of the vehicle that passes, including the date, time, weight of the vehicle, and the status of whether the vehicle exceeds the load limit or not. This data is presented in tabular form for easy monitoring and analysis, with the status marked in green for "Not Exceeding Load" and red for "Exceeding Load". This makes it easier for users to see the history of vehicles crossing the bridge quickly and effectively.

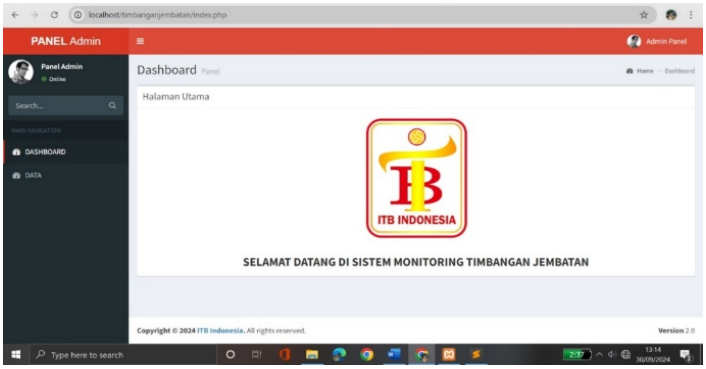

Fig 2. Initial view of the Website

Figure 2 displays the system or organization's logo as the main element on the home page, used as a splash screen before accessing further information or functionality of the system.

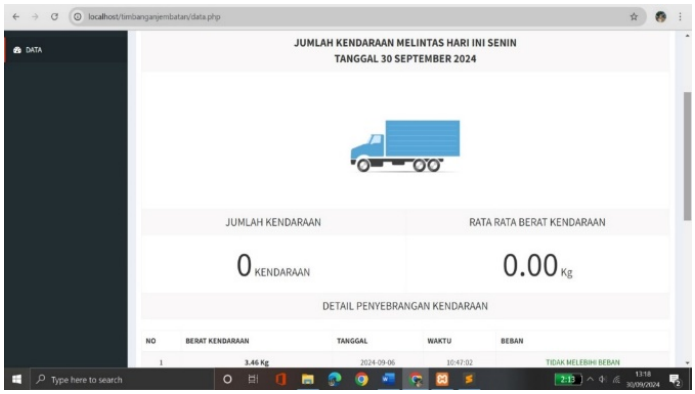

Fig 3. Website Display Number of Vehicles

Figure 3 shows daily data on the number of vehicles passing through and the average weight of vehicles per day. Every day, the system records how many vehicles pass on the bridge and calculates the average weight of the entire vehicle. This information is clearly presented to monitor the traffic and loads received by the bridge, aiding in the supervision and early detection of overloads that may impact the infrastructure.

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

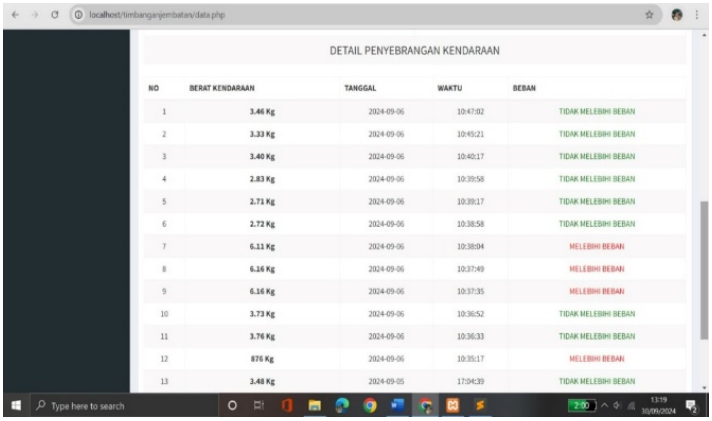

Fig 4. Website Display of Weight Detection Results

Figure 4 shows a table of vehicle weight detection results on an Arduino-based system accessed through a website (localhost). This table contains detailed information about the vehicle's weight, date, time, and load status (whether or not it exceeds the permissible limit). The table shows some vehicles with weights measured in kilograms (Kg), as well as statuses marked in two colors: green for "Not Overloaded" and red for "Overloaded". This system is used to monitor the weight of vehicles crossing the bridge in real-time.

DISCUSSIONS

At this stage, there will be a discussion about the system in the form of testing and how the system itself works. This is done to find out whether the functions of the tools and systems that have been designed can work well or not. Testing the tool is also useful to find out the level of performance and functionality. The tests carried out include hardware testing and system testing. Hardware testing is carried out to find out how the designed hardware performs. This test includes:

Arduino Uno Network Testing

Programming using the Arduino circuit with 32+ expansion modules, Arduino 32+ is an expansion module for the Arduino development board designed to improve the capabilities and functionality of the system. This module allows the addition of various sensors, actuators, and other devices without the need for many additional cables or connections. The Arduino is equipped with a Wi-fi module that makes it easy to integrate with the device. Testing on this device is carried out by connecting this circuit to the power supply circuit, ensuring that all components are working properly. Below is a picture of the results of the Arduino test.

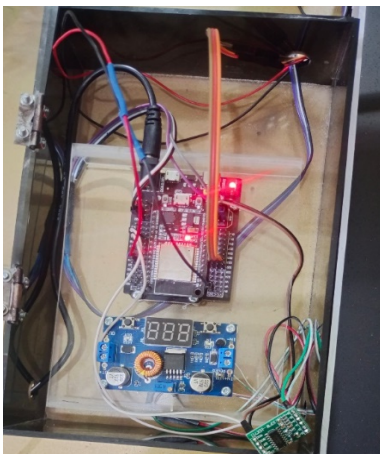

Fig 5. Testing on the Arduino Network

Figure 5 is a test of the Arduino circuit connected to the power supply, step down, load cell, and HX711 module by involving connection and voltage checks to ensure all components are connected and functioning correctly.

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

LCD Testing

At this stage, an experiment is carried out to activate the system's LCD. This LCD activation is done by displaying several characters on the LCD. In the truck load detection system, the author uses a 2x16 LCD series. A 2x16 LCD is an LCD screen that can display two lines of text, each consisting of 16 characters. These screens are often used in various Arduino and embedded system projects due to their ease of use and ability to display text information clearly. The 2x16 LCD display functions as a message viewer in the form of LCD characters used in this tool has a display width of 2 rows of 16 columns, or commonly referred to as LCD Character 2x16, with 16 connector pins, which is defined as follows:

Table 1
Function of the 2x16 LCD Character pin

PIN	Name	Function
1	VSS	Ground voltage
2	VCC	+5V
3	CATTLE	sContrast voltage
4	RS	Register Select, 0 = Instruction Register, 1 = Data Register
5	R/W	Read/Write, to choose write or read mode, 0 = write mode, 1 = read mode
6	E	Enable, 0 = start to laugh data to lact. Character, 1 = disable
7	DB0	LSB
8	DB1	-
9	DB2	-

Table 1 provides a brief description of the functions of each pin on a 2x16 Character LCD, which is commonly used in various electronics and Arduino projects. All of these pins work together to display characters or text according to commands from the Arduino. Figure 6 below is a picture of the results of the LCD test:

Fig 6. Testing On LCD

Figure 6 is the test result on the LCD, which shows the results of the truck exceeding the predetermined load.

Servo Motor Network Testing

Testing on this servo motor circuit is performed by connecting the circuit with an Arduino and connecting the output of this circuit with a servo motor to drive the swing arm so that the door can open. This mechanism allows for precise and responsive control of load changes, ensuring that the system remains in optimal working condition. Below is a picture of the servo motor test results:

JCEIT: Journal of Computer Engineering and Information Technology
Volume 2, Number 2, March 2026
Page: 160-169
ISSN 3089-106X
(online)

Fig 7. Servo motor testing

Figure 7, It is the result of a servo motor test where the servo motor functions as an automatic bar controller that can open and close based on the load it receives. If the received load exceeds the predetermined capacity, the servo motor will automatically close the bar to prevent further loading. Conversely, if the load does not exceed capacity, the servo motor will open the bar, allowing for safe and efficient operation.

Alarm Testing

The alarm used is a 5V high-active buzzer. When the ultrasonic sensor detects a weight that exceeds the maximum load limit, the buzzer will sound to warn the truck that it is overloaded.

CONCLUSION

Based on the results of the study, it can be concluded that the way to design an Arduino-based truck load detection system involves the identification of components such as Arduino, load cells, and HX711 modules, followed by designing a connection scheme between components. Load cells are installed under the bridge to detect loads, while the HX711 module is connected to the Arduino to process the signal. After that, create a program in the Arduino IDE, calibrate the load cells, and test the system with a passing truck. If it is accurate, the system is permanently installed to monitor the weight of trucks passing on the bridge.

The hardware design uses Arduino, which involves installing a load cell to detect a load, an HX711 module to amplify the signal from the load cell, and an Arduino to process data. All components are electronically connected, with the Arduino set up to read and calculate the weight of the load, while the hardware implementation using Arduino that is that involves steps such as assembling and connecting all the components according to the design scheme that has been created. To create a warning system for overloaded trucks, connect the load cell to the HX711 module and connect it to the Arduino. The Arduino program to read the weight of the Load cell and the buzzer will activate an alarm if the load exceeds the specified limit. Test and calibrate to ensure measurement accuracy and alert function.

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* Delima Astuti Rambe, et.all

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Volume 2, Number 2, March 2026
Page: 160-169
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