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Design and Implementation of a Microcontroller-Based Automatic Weighbridge Prototype for Vehicle Detection and Weight Measurement

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Abstract

Truck weighbridges play an important role in monitoring vehicle loads to ensure traffic safety and protect road infrastructure from damage caused by overloading. However, conventional systems still have limitations, such as dependence on operators, non-automated data recording, and relatively high implementation costs. This study aims to design and develop a microcontroller-based automatic weighbridge prototype for educational and simulation purposes.
The system uses an Arduino Mega 2560 as the main controller, a load cell with an HX711 module for weight measurement, an E18-D80NK proximity sensor for vehicle detection, and a TCS3200 color sensor for vehicle color identification. It also integrates a servo motor for the automatic barrier, a buzzer as an indicator, an LCD for information display, an RTC DS3231 module for time recording, and an SD Card module for offline CSV data storage.
Test results show the system operates automatically with measurement errors ranging from 0.25% to 1%, demonstrating good accuracy and effectiveness as a small-scale weighbridge prototype.

Keywords:
weighbridge;
Arduino Mega 2560;
load cell;
HX711;
SD Card;

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1. Introduction

A weighbridge is an essential facility in land transportation systems that functions to measure vehicle weight in order to prevent overloading. Overloaded vehicles can cause damage to road structures, accelerate the deterioration of transportation infrastructure, and increase the risk of traffic accidents. Therefore, vehicle weight monitoring plays a crucial role in supporting road safety and maintaining the sustainability of transportation infrastructure.

However, conventional weighbridge systems still face several challenges in practice. The weighing process generally relies on human operators, while data recording is often performed manually or through semi-digital methods. These conditions may lead to recording errors, reduce operational efficiency, and result in relatively high implementation and maintenance costs. Furthermore, conventional weighbridge systems are typically large and complex, making them less suitable for use as educational tools or simulation media in academic environments.

Advances in microcontroller technology, particularly the Arduino platform, provide opportunities to develop automatic weighbridge systems that are more affordable, operate independently without requiring internet connectivity, and can be easily customized according to specific requirements. The use of load cell sensors combined with the HX711 module enables digital weight measurement with a satisfactory level of accuracy. In addition, the integration of a proximity sensor allows automatic vehicle detection, while a Real-Time Clock (RTC) module and an SD Card module facilitate real-time data logging and local data storage.

Based on these challenges, there is a need for a miniature-scale automatic weighbridge system capable of performing vehicle detection, weight measurement, and automated data recording without dependence on operators or internet connectivity. Therefore, this study focuses on the design and development of an Arduino Mega 2560-based automatic weighbridge prototype equipped with a load cell sensor, a proximity sensor, an RTC module, and an SD Card module for data storage. The proposed system is expected to serve both as a functional prototype and as an educational simulation platform for small-scale weighbridge applications.

2. Methods

The design phase illustrated in Figure 1 consists of the hardware integration process involving four load cells interfaced with an HX711 module, a DS3231 Real-Time Clock (RTC) module, a 16×2 I2C Liquid Crystal Display (LCD), a buzzer, an E18-D80NK proximity sensor, an SD Card module, a TCS3200 color sensor, an SG90 servo motor, LEDs, and an Arduino Mega 2560 microcontroller. The electronic circuit schematic and system layout were designed using Fritzing software.

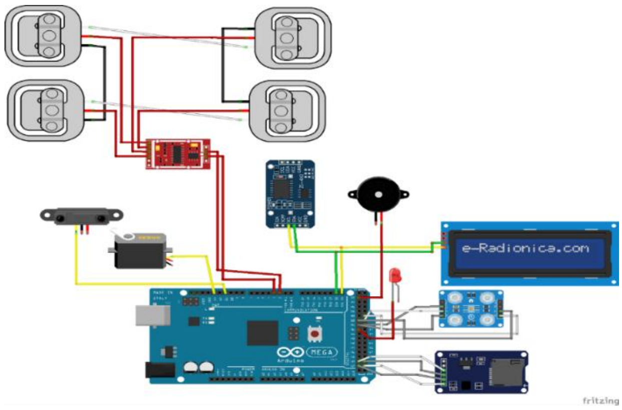

Fig. 1. Schematic and System Layout

Block Diagram

The block diagram illustrates the flow of data and control signals throughout the system. Sensor-generated data are used as input and processed by the microcontroller, which functions as the central control unit. The processed information is then transmitted to the actuators and display devices, serving as the output components of the system.

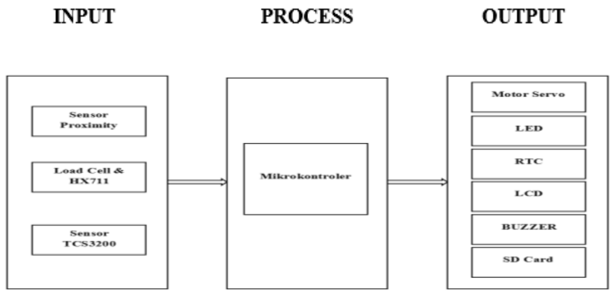

Fig. 2. Block D iagram.

Prototype design

The automatic weighbridge prototype serves as a simulation platform designed to illustrate the operational mechanism of a weighbridge system for vehicle detection, vehicle weight measurement, and automated data logging. The prototype integrates several hardware components, including load cell sensors, an HX711 module, a proximity sensor, a TCS3200 color sensor, an RTC module, an SD Card module, a servo motor, an LCD, a buzzer, and an Arduino Mega 2560 microcontroller. These components work in a coordinated manner to establish a fully integrated system capable of performing automatic weighing and data acquisition processes.

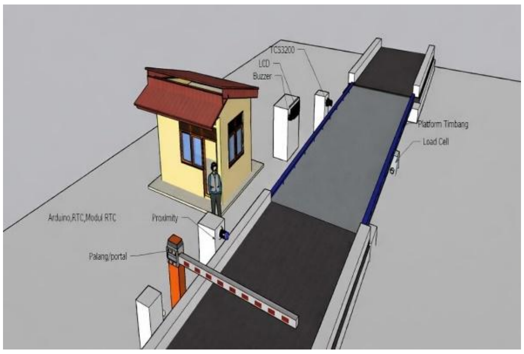

Fig. 3. Prototype design

Operational Workflow

The system begins operating when electrical power is supplied and the program on the Arduino Mega 2560 is executed. During the initialization stage, the microcontroller configures all connected components, including the load cell sensors with the HX711 module, proximity sensor, TCS3200 color sensor, servo motor, LCD, buzzer, DS3231 Real-Time Clock (RTC), and SD Card module, to ensure that each device is functioning properly and ready for operation.

After initialization, the system enters a standby mode and continuously monitors the proximity sensor for the presence of an approaching vehicle. Once a vehicle is detected, the servo motor opens the barrier gate, allowing the vehicle to enter the weighing platform. The system then measures the vehicle's weight using the load cell sensors and identifies its color through the TCS3200 sensor.

The measured weight is subsequently compared with the predefined load limit. If the vehicle weight is within the allowable range, the measurement data are displayed on the LCD and stored on the SD Card. Conversely, if the measured weight exceeds the specified limit, the buzzer is activated as a warning indicator, while the overload data are still recorded and saved to the SD Card.

Upon completion of the weighing process, the vehicle exits the weighing area, the barrier gate closes automatically, and the system returns to standby mode, ready to detect and process the next vehicle.

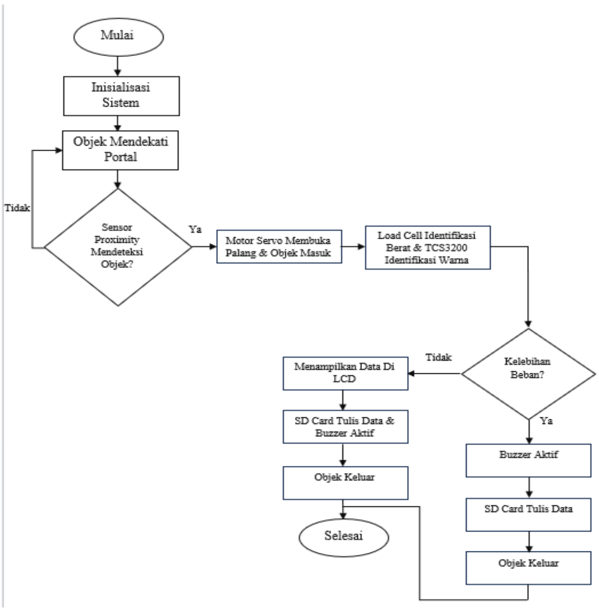

Fig. 4. Operational workflow

3. Results and Discussion

Load Cell Testing

The load cell testing procedure was carried out by comparing the weight measurements obtained from the load cell system with those measured using a digital reference scale. The purpose of this test was to assess the accuracy of the load cell and determine the level of agreement between the prototype measurements and the reference measurements.

The load cell sensor was tested by applying a 1 kg test load that had been previously verified using a digital weighing scale as the reference measurement. Based on the LCD reading shown in Figure 5, the automatic weighbridge system displayed a weight of 1.040 kg. This value differed slightly from the measurement obtained using the digital scale, which recorded a weight of 1.043 kg, indicating a relatively small measurement deviation between the two readings.

Fig. 5 Load Cell Testing 1

The percentage error was calculated using the following equation:

$$Error\ (\%) = \frac{|1,040 - 1,043|}{1,043} \times 100\% = 0,23\%$$

Fig. 6 Load Cell Testing 2

Based on the reading displayed on the LCD screen shown in Figure 5, the measured weight was 3.99 kg (3,990 g). This value is slightly lower than the actual weight of 4.00 kg (4,000g), indicating the presence of a measurement deviation.

The percentage error was calculated using the following equation:

$$Error\ (\%) = \frac{|4{,}000 - 3{,}990|}{4{,}000} \times 100\% = 0{,}25\%$$

Based on the calculation, the measurement error was determined to be 0.25%. The observed deviation may be attributed to several factors, including sensor sensitivity, signal fluctuations from the load cell, and the mechanical characteristics of the weighing platform.

A comprehensive summary of the testing results is provided in Table 1.

Table 1. Load Cell Testing Results

No	Berat Aktual (Kg)	Berat Terbaca Timbangan Digital WH-B05 (Kg)	Berat Terbaca Load Cell(Kg)	Error (%)
1	1	1,048	1,040	0,23
2	2	2,000	2,010	0,5
3	3	3,046	3,080	1,11
4	4	4,000	3,990	0,25
5	5	5,000	5,010	0,2

E18-D80NK Proximity Sensor Testing

The E18-D80NK proximity sensor was tested to evaluate its detection capability and effective sensing range for detecting the presence of vehicles.

Fig. 7 E18-D80NK Proximity Sensor Testing

The test results are presented in Table 2.

Table 2. E18-D80NK Proximity Sensor Testing

Jarak Objek (Cm)	Status Sensor	Keterangan Objek
1	Aktif	Terdeteksi dan Stabil
2	Aktif	Terdeteksi dan Stabil
3	Aktif	Terdeteksi dan Stabil
4	Aktif	Terdeteksi dan Stabil
5	Aktif	Terdeteksi dan Stabil
6	Aktif	Terdeteksi dan Stabil
7	Aktif	Terdeteksi dan Stabil
8	Aktif	Terdeteksi dan Stabil
9	Aktif	Terdeteksi dan Stabil
10	Aktif	Terdeteksi dan Stabil
11	Aktif	Terdeteksi dan Stabil
12	Aktif	Terdeteksi dan Stabil
13	Aktif	Terdeteksi dan Stabil
14	Aktif	Terdeteksi dan Tidak Stabil
15	Aktif	Terdeteksi dan Tidak Stabil
16	Aktif	Terdeteksi dan Tidak Stabil
17	Aktif	Terdeteksi dan Tidak Stabil
18	Tidak Aktif	Tidak Terdeteksi
19	Tidak Aktif	Tidak Terdeteksi
20	Tidak Aktif	Tidak Terdeteksi

Based on the results shown in Table 2, the E18-D80NK proximity sensor demonstrated good object detection performance within a distance range of 1 cm to 17 cm. Between 1 cm and 13 cm, the sensor provided stable and consistent detection responses. Meanwhile, at distances greater than 13 cm up to 17 cm, objects could still be detected; however, the stability of the sensor response began to decrease. At a distance of 18 cm, the sensor accuracy declined significantly, resulting in unreliable detection performance.

These results indicate that the optimal operating range of the E18-D80NK proximity sensor is between 1 cm and 13 cm. Therefore, in the implementation of the miniature-scale automatic weighbridge system, the sensor was installed within this range to ensure accurate and consistent vehicle detection.

TCS3200 Color Sensor Testing

The TCS3200 color sensor was evaluated to verify its ability to measure RGB (Red, Green, Blue) values and accurately recognize object colors. In this experiment, the distance between the sensor and the target object was varied to assess its influence on the sensor's color detection performance. The results demonstrate that the sensor's accuracy in color recognition is affected by the measurement distance, making proper sensor placement an important consideration for achieving reliable color identification.

Fig. 8 Red Object Testing

Fig. 9 Orange Object Testing

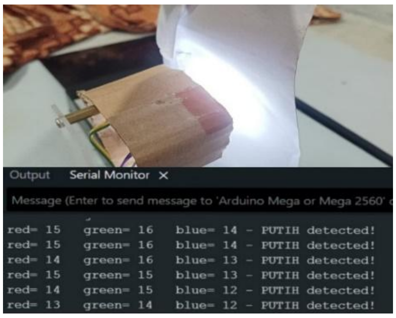

Fig 10 White Object Testing

System Testing

The system testing process encompassed several operational functions, including vehicle detection, weight measurement, automatic barrier gate operation, information display through the LCD, and data storage using the SD Card module. The purpose of this testing was to verify that all hardware and software components operated in accordance with the designed system architecture and workflow.

During the testing procedure, a miniature vehicle with additional loads was used to simulate a loaded vehicle. Based on the test results, the system successfully performed all intended functions, including vehicle detection, weight measurement, barrier gate control, and data logging. Therefore, the automatic weighbridge prototype can be considered to have achieved its intended objectives and is suitable for use as a simulation and educational platform.

1. The testing procedure was conducted using a orange miniature vehicle with an additional load to simulate a loaded vehicle. While positioned on the weighing platform, the load cell and HX711 module measured a weight of 3.47 kg, while the TCS3200 sensor successfully identified the vehicle color as green. This measured weight was close to the established limit of 4 kg, which is equivalent to approximately 8 tons under real-world conditions for Class II and Class III roads. Therefore, the vehicle was still permitted to pass, although it was approaching the maximum allowable road load capacity.

The measured weight, vehicle color, and weighing timestamp were displayed in real time on the LCD and automatically recorded on the SD Card in CSV format. The test results demonstrated that all system components operated in an integrated manner and performed according to the intended design. Documentation of the testing process is presented in Figure 11.

Fig 11. System Testing 1

2. The testing procedure was conducted using a miniature vehicle with an additional load to simulate a loaded vehicle. While positioned on the weighing platform, the load cell and HX711 module measured a weight of 2.26 kg. This value was below the established limit of 4 kg, indicating that the vehicle represented a normal load condition that complied with the Maximum Permissible Axle Load (MST) requirements for Class II and Class III roads and was also considered safe for operation on Class I roads. Therefore, the system classified the vehicle as having a normal load.

Documentation of the testing process is presented in Figure 12.

Fig 12. System Testing 2

3. The testing procedure was conducted using a black miniature vehicle with an additional load to simulate a heavily loaded vehicle. While positioned on the weighing platform, the load cell and HX711 module measured a weight of 4.23 kg, while the TCS3200 sensor successfully identified the vehicle color as black. Since the measured weight exceeded the predefined limit of 4 kg, the vehicle was classified as overloaded and considered equivalent to a load exceeding 10 tons, thereby violating the Maximum Permissible Axle Load (MST) regulations.

Under this condition, the system activated the buzzer, displayed an overload warning message on the LCD, and recorded the violation data on the SD Card. The vehicle weight, color, and weighing timestamp were displayed in real time and automatically logged in CSV format. The test results demonstrated that all system components operated in an integrated manner and performed according to the intended design. Documentation of the testing process is presented in Figure 13.

Fig 13. System Testing 3

A comprehensive summary of the testing results is provided in Table 3.

Table 3. System Testing Results

Waktu	Warna Kendaraan	Berat (Kg)	Status Berat Kendaraan	Status Palang
Minggu, 2026-01-04, 22:39:02	Oren	3,47	Normal	Tutup
Minggu, 2026-01-04, 22:36:12	Hijau	2,26	Normal	Tutup
Minggu, 2026-01-04, 22:42:09	Hitam	4,23	Overload	Tutup
Senin, 2026-01-26, 12:05:39	Hitam	3,36	Normal	Buka
Senin, 2026-01-26, 15:21:25	Hijau	4,20	Overload	Buka
Senin, 2026-01-26, 15:23:37	Oren	3,19	Normal	Buka
Senin, 2026-01-26, 15:26:47	Hitam	4,62	Overload	Buka

Table 3 summarizes the testing results of the automatic weighbridge system, including the measurement timestamp, vehicle color, vehicle weight, load status, and barrier gate status. The recorded data were automatically generated from load cell sensor measurements and processed through the integrated control and data acquisition system.

The results indicate that the load cell sensor provided reliable weight measurements, while the control system accurately classified vehicle load conditions and controlled the barrier gate operation. In addition, the automatic data logging functionality operated successfully, demonstrating the system's capability to support efficient weighbridge monitoring and performance evaluation.

4. Analysis And Conclusions

Analysis

Based on the sensor and system testing results, the automatic weighbridge system operated in accordance with the intended design. The E18-D80NK proximity sensor successfully detected vehicles within an effective range of up to 13 cm and triggered the Arduino Mega 2560 to open the barrier gate via the servo motor. The load cells, interfaced with the HX711 module, successfully measured vehicle weights of 2.26 kg (orange), 3.47 kg (green), and 4.23 kg (black), although minor measurement deviations were observed.

The system was also capable of classifying vehicles into normal-load and overload categories based on the predefined parameters. The TCS3200 color sensor successfully identified vehicle colors according to their RGB values, while the LCD displayed the weight measurements in real time. Furthermore, the DS3231 Real-Time Clock (RTC) module accurately recorded the date and time of each measurement, and all relevant data—including timestamp, vehicle color, vehicle weight, load status, and barrier gate status—were automatically stored in CSV format on the SD Card.

After the weighing process was completed, the barrier gate automatically returned to the closed position, indicating that the entire control system functioned optimally and that all hardware and software components were well integrated.

Conclusions

Based on the design, implementation, testing, and evaluation of the microcontroller-based automatic weighbridge prototype, the following conclusions can be drawn:

1. The Arduino Mega 2560-based automatic weighbridge prototype was successfully designed and implemented in accordance with the objectives of this study. The system was capable of operating automatically and in an integrated manner.
2. The testing results of the load cell sensors integrated with the HX711 module demonstrated that the system was capable of measuring loads within a range of 1 kg to 5 kg, with measurement errors ranging from 0.25% to 1.11%. These errors may be attributed to signal noise and mechanical vibrations, which can affect the stability of the sensor readings.
3. The E18-D80NK proximity sensor was able to detect the presence of vehicles reliably within its effective operating range.
4. The SD Card module functioned effectively in recording timestamp information and automatically storing weighing data in CSV format.

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