Prototype Development of RFID-Based Truck Load Data Collection Tool with Smart Calibration and HMI Methods

Muhammad Erik Ardiansyah*[1], **Denny Irawan**[2]
Universitas Muhammadiyah Gresik, Jl. Sumatera No. 101 GKB, Kabupaten Gresik, Jawa Timur, Indonesia, (031) 3951414
*E-mail : erikardiansyah48@gmail.com**[1], *den2mas@umg.ac.id*[2]
**Corresponding author*
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Abstract - With the advancement of technology, humans are also required to adapt to these advancements. The industrial sector is one sector significantly impacted by this technological development, from increasingly sophisticated production machines to increasingly flexible attendance systems for employees. However, amidst this technological advancement, the author found several aspects impractical in its application. One example is the use of paper documents for loading and unloading trucks. The use of paper documents can complicate the loading and unloading process, as paper documents have several weaknesses, such as water fading, tearing, forgery, and other weaknesses not included in this study. Based on these issues, the researcher taking the initiative to create a prototype of an RFID-based truck load data collection tool with smart calibration and HMI that facilitates truck drivers and warehouse personnel in the loading and unloading process. The system researcher designed consists of an RFID sensor connected to an Haiwell Scada.

Keywords - Paper, RFID, Prototype, smart calibration, HMI, Truck

1. INTRODUCTION

Industry is a field inextricably linked to technological advancements. Simultaneously, many departments are beginning to address technological advancements in the industrial world, from modernizing production equipment and security surveillance to modernizing employee attendance. However, amidst this technological advancement, researchers encountered a significant impracticality in the logistics sector, where goods frequently enter and exit trucks.Researchers found truck drivers carrying paper-based loading and unloading documents. This makes these documents susceptible to damage, complicating the loading and unloading process. Based on this issue, researchers initiated the development of a RFID based truck load data collection tool with smart calibration and hmi that facilitates both truck drivers and logistics personnel in the loading and unloading process. This system, designed to minimize paper usage, also avoids losses caused by paper documents, such as water fading, tearing, falsification, and other losses not covered in this study. Of course, before going any further, researchers gathered several references that researchers will use in my future system [1]–[6].

Here are some previous studies discussing the RFID system and Haiwell Cloud Scada. The study entitled "Prototype Monitoring Tool Measuring Volume and Weight of Loads on IoT-Based Trucks" This study discusses a tool for monitoring the volume of cargo bodies and the weight of loads on IoT-based loaded vehicles with RFID as a data collection tool. This tool can make it easier for companies to control the loads to be shipped. Thus, it can reduce the risk of overloading on vehicles. The research method is to conduct tests using objects in the form of boxes to measure their volume and weight. How this prototype works: Ultrasonic sensors measure the length, width, and height to determine the volume of the load, and the load cell sensor measures the weight of the truck load. The RFID sensor detects the truck driver's ID card. And from the data obtained, it will be processed by the ESP82266 microcontroller and sent and stored

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in the Google Sheet application. The results of the load cell sensor readings are 87.4% for weight measurement and the SRF04 sensor is 98.5% [7].

The second research entitled "Design and Construction of a Close House Chicken Coop Central Control System Based on Arduino and Haiwell Cloud Scada" This research discusses the Close House Chicken Coop control system based on Arduino and Haiwell Cloud Scada which is centralized in 2 close house chicken coops to make it easier for broiler chicken entrepreneurs to monitor and control the close house chicken coops owned by the entrepreneur through one place, without having to go directly to the close house chicken coop to monitor and control the chicken coop which of course will be quite draining time and energy. This research uses Haiwell Cloud Scada as an interface device connected to the Arduino Nano microcontroller, DHT-22 sensor as a humidity and temperature detector sensor, MQ-135 sensor as an Ammonia gas detector, water level sensor as a reader of the remaining level of chicken drinking water, IR sensor as a reader of the remaining level of chicken food, DC fan which has 2 functions namely inlet and exhaust in the chicken coop. Servo motor as a silo damper controller to fill chicken food from the silo to the chicken feeder located in the chicken coop. In this study, the HMI used was highly effective, allowing researchers to use it as a reference for the HMI interface system [8].

The third study, entitled "Designing the Application of RFID Technology to Improve Tracking and Quality Assurance in the Kpbs Pangalengan Pure Milk Supply Chain," discusses the design of RFID implementation for dairy cows, feeding, milk production, and fresh milk distribution. Data collection was conducted through field observations, interviews with relevant parties, and documentation analysis. The results showed that RFID implementation improved operational efficiency, supply chain transparency, and dairy product quality assurance. In this study, the RFID system used proved that RFID can improve milk distribution efficiency, leading researchers to decide to use RFID technology [9].

In the first research reference, the calibration method used is still Ordinary (Span Calibration) so that calibration requires the use of the original dead weight placed on the sensor. This method does have high accuracy, but when used for truck scale calibration, it requires a lot of time, energy, and space to move the physical load. Therefore, researchers chose Smart Calibration as a calibration method because in this method, calibration is done digitally via HMI without the need to lift physical loads, thus saving time, energy, and space required for calibration and not hindering the work of the weighbridge admin. This method is carried out by entering the loadcell specification data and its supporting components (HX711) from the datasheet; the parameters used are sensitivity (mV/V) and maximum capacity.

2. RESEARCH METHOD

The research method is the research planning stage for implementing the system being created. The first research planning stage is system design, system implementation, and finally, system testing. The tool that the researcher designed consists of the main component, ESP32, as the main microcontroller; ESP32 programming is done through Arduino IDE software. RFID sensor type RC522 as a data reading sensor on the RFID card. Single point loadcell 10 kg to weigh the truck load, the loadcell sensor reading needs to be converted into digital, therefore the HX711 module is used, this module is usually installed in a package when purchasing a loadcell. Then, to design the HMI interface, Haiwell SCADA software is used [10]–[15].

2.1 Smart Calibration

In this study, researchers used Smart Calibration technology as a method for calibrating load cell sensors. Smart Calibration is a digital calibration method that relies on calculated sensor sensitivity parameters to achieve measurement accuracy. Compared to conventional methods, this system minimizes physical interaction with the standard load by converting the Rated Output (mV/V) value in the sensor datasheet, which is processed directly by the microcontroller.

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2.2 Component Datasheet

This measurement system consists of an integration of main components with the following datasheet [16], [17]:

Table 1 Single point load cell datasheet

No.	Parameter	Value	Unit
1	Maximum capacity (EMAX)	10	Kg
2	Output sensitivity (= FS)	2.0 ± 0.2	mV/V
3	Sensor accuracy	C3	–

Table 2 HX711 module datasheet

No.	Parameter	Value	Unit
1	Gain	128	–
2	ADC Resolution	24	Bit
3	Operating voltage	2.6 ~ 5.5	V
4	Operating current	< 1.5	mA

2.3 Formula

The smart calibration process begins with a formula to calculate the maximum output voltage (V_{OUT}) and the calibration factor (CF). The formula is[18]–[20]:
Maximum output voltage (V_{OUT})

$$V_{out} = V_{exc}\ x\ S \qquad (1)$$

Calibration Factor (CF)

$$CF = \frac{\left(\frac{S}{1000}\right) x\ Gain\ x\ 2^{23}}{E_{max}} \qquad (2)$$

Description
S : Loadcell sensor sensitivity according to datasheet (mV/V)
Gain : HX711 sensor gain according to datasheet (128)
E_{MAX} : Maximum loadcell sensor capacity according to datasheet (10kg)

2.4 Measured weight equation (W)

Once the calibration factor (CF) is known, the ESP32 microcontroller will calculate the weight using the following formula :

$$W = \frac{Raw\ data - Offset(Tare)}{CF} \qquad (3)$$

Description :
W : Loadcell sensor reading at any time
Raw data : The digital value of the raw reading by the HX711 (when loaded)
Offset(Tare) : The digital value of the HX711's empty scale reading
CF : Calibration factor
The result of the ESP32's calculation of this formula is the loadcell sensor reading at any time.

2.5 Smart Calibration Procedure

The Smart Calibration procedure involves the following steps:

1. Record the maximum capacity (kg) and theoretical sensitivity (mV/V) values listed in the sensor datasheet.
2. Enter the sensor datasheet parameters into the algorithm variables in the Arduino IDE to calculate the Calibration Factor (CF).
3. Run the device under no-load conditions (empty) so the system can automatically perform the tare function to establish the zero point.
4. Take a real-time load reading, where the system automatically converts the digital signal into weight units based on the results of a predetermined formula (W).

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2.6 System Design

The following is a system design created by researchers. This system design includes a brief explanation of the system workflow.

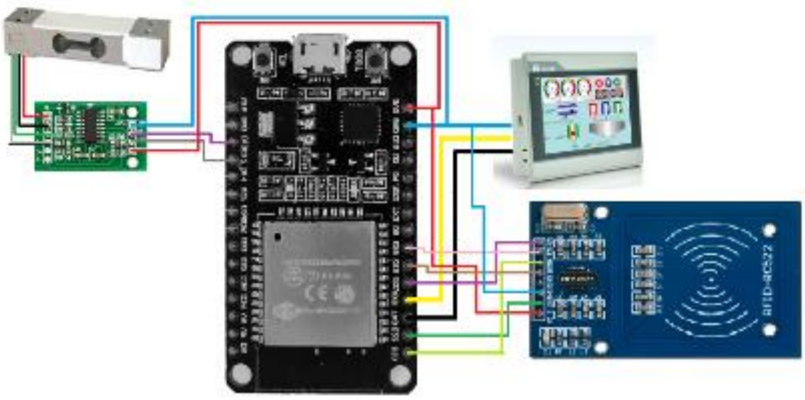

Figure 1 wiring diagram of the designed tool

As can be seen from Figure 1, the device designed by the researcher is quite simple. It consists of ESP32 as the main microcontroller, Loadcell and HX711 module as a set of sensors for weighing, HMI Scada as an interface that facilitates control. Communication between ESP32 and HMI Scada uses RS232. Details of the connection pins can be seen in Table 1 below.

2.7 Microcontroller Input Output

This chapter explains the details of the connection pins of the designed tool and several sensor configurations.

Table 3 connection pin details

RFID PIN	ESP32 PIN	LOADCELL PIN	HX711 PIN
SDA	GPIO 21	RED	E+
SCK	GPIO 18	BLACK	E
MOSI	GPIO 23	GREEN	A+
MISO	GPIO 19	WHITE	A
GND	GND		
RST	GPIO 22		
VCC	3,3 V		
ESP32 PIN	HMI	HX711 PIN	ESP32
3,3 V	VCC	GND	GND
GND	GND	DT	GPIO 15
RX	TX	SCK	GPIO 2
TX	RX	VCC	3,3 V

2.8 Flowchart Diagram

The following is a flowchart diagram of the tool designed by the researcher.

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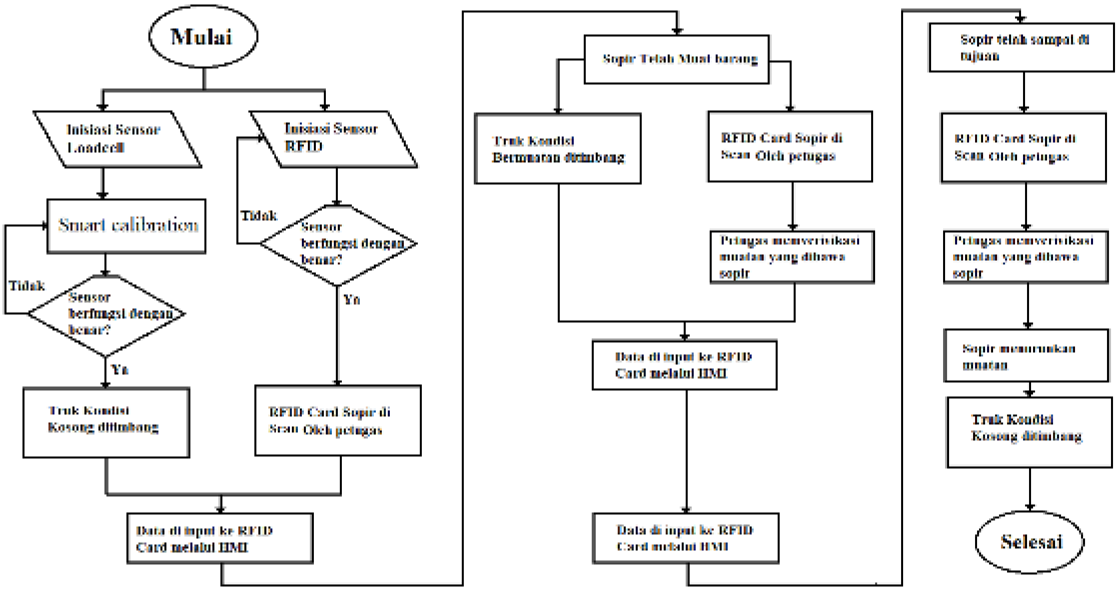

Figure 2 Flowchart diagram

Figure 2 shows a flowchart of the designed system, where the system functions are divided into three parts:

1. Register
- In this section, the system starts, then the RFID sensor and load cell are initialized. If the load cell sensor reading does not match the load used for checking, calibration is required.
- When the truck arrives, the empty truck's weight is weighed, and the driver's RFID card is scanned by an officer. The officer inputs the driver's personal data and the truck's license plate.
- The empty truck's weight, driver's personal data, and license plate are then input into the RFID card via Haiwell SCADA, and the driver is authorized to load.

2. Input
- The driver who has loaded the truck reports to the officer.
- When the truck arrives, the loaded truck's weight is weighed, and the driver's RFID card is scanned by an officer. The officer inputs the driver's load data and verifies the goods.
- The loaded truck's weight and cargo data are then input into an RFID card via Haiwell SCADA, and the driver is allowed to leave the area with the cargo to its destination.

3. Check
- The truck arrives with the cargo.
- Upon arrival, the truck's weight is weighed, and the driver's RFID card is scanned by an officer. The officer checks the cargo data and verifies the goods.
- If the goods match the data on the RFID card, the driver is allowed to unload the goods at the warehouse.

At the Sensor Calibration stage, the Smart Calibration method is used where the Calibration Factor is calculated theoretically by the ESP32 based on the 10kg sensor specification data, so that the process can immediately proceed to weighing the empty truck without additional standard loads.

3. RESULTS AND DISCUSSION

The next step is to create the designed tool, then proceed with the tool testing stage. Things analyzed when testing this tool include testing the suitability of Loadcell readings with

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reference weights, the accuracy of RFID input data and the effect of card conditions on data reading, data retrieval and upload via HMI SCADA. On the next page, the test results for the haiwell scada and rfid based load truck data recording tool are presented.

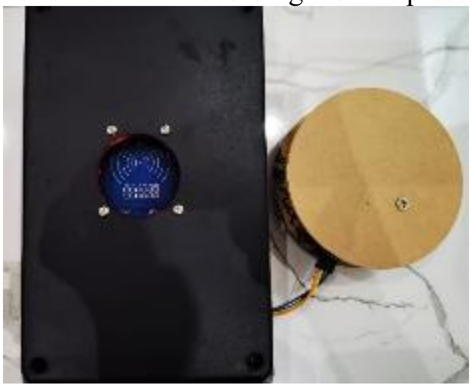

Figure 3 the results of the prototype realization by researchers

3.1. RFID Testing

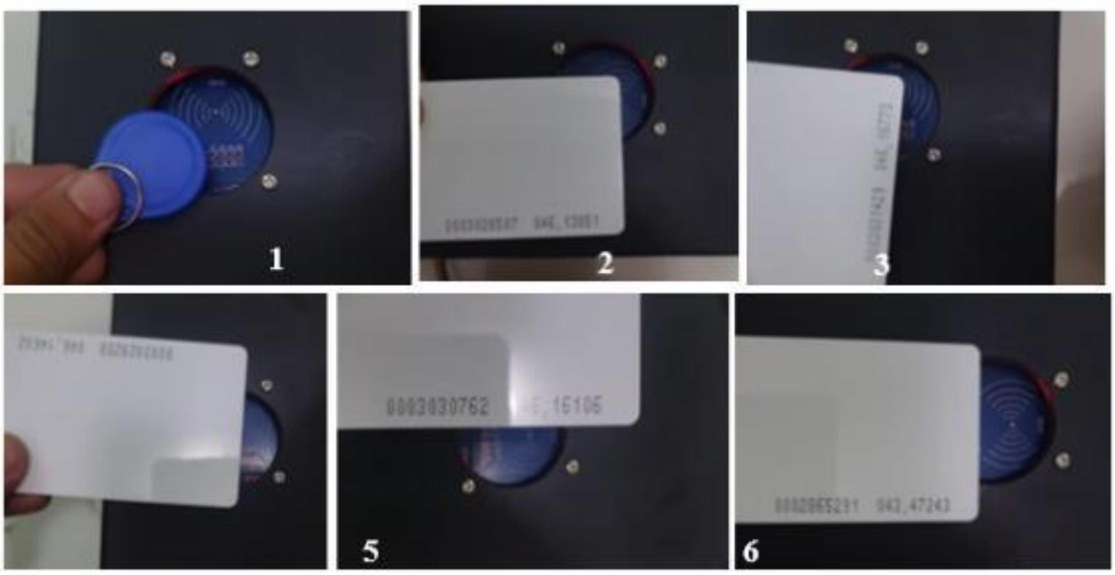

Figure 4 RFID Testing

Figure 4 shows the process of testing the RFID sensor function and the following data was obtained :

Table 4 RFID sensor testing result based on card position

No	RFID card/tag position	Reading status	Data correct?	Notes
1	Center	Succes	Yes	The tag chip and reader are perfectly aligned
2	Center (Vertical)	Succes	Yes	The card chip cross sectional area covers the entire sensor area
3	Center (Horizontal)	Succes	Yes	Induction continues even if the card orientation changes
4	Left side (Hroizontal)	Succes	Yes	Part of the chip area remains within the field range
5	Left side (Vertical)	Succes	Yes	Part of the chip area remains within the field range
6	Bottom edge	Failed	No	Misalignment occurs, resulting in insufficient induction power

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Figure 5 RFID Testing

Table 5 RFID sensor testing result based on card range from RFID tap/sensor point

No	Distance (cm)	Reading status	Data correct?	Notes
1	0	Succes	Yes	The card is close to the sensor surface, resulting in maximum magnetic induction and very stable data transfer.
2	1 – 2	Succes	Yes	The card hovers slightly above the sensor, but the electromagnetic field is still strong enough to power the card chip and allow data transfer.
3	>3	Failed	No	The card is too far from the sensor, causing the induction force to weaken drastically because the distance exceeds the operational threshold of the RC522/PN532 sensor.

Based on the test results in tables 2 and 3, it can be concluded that the RFID reading system has a high level of dependence on position precision and operational distance, where card scanning only runs optimally at a maximum distance of 2 cm with the card/tag chip position aligned directly above the center point of the sensor. Failure to read the card/tag occurs when it is in an off-center position and the distance between the card/tag is more than 3 cm. This proves that there is a limitation of the sensor's electromagnetic field in inducing the card/tag chip, so it is recommended to add a card tapping instruction sticker on the surface of the device so that truck drivers can tap accurately to ensure the speed and validity of load data collection.

3.2. Loadcell Testing

Figure 6 Loadcell

Figures 6 are loadcell sensor, this chapter we will begin loadcell sensor test. Please note that this load cell has been calibrated. The calibration process will be explained in the next chapter. The sensor test results data are presented in the following figures and table:

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Figure 7 Conventional weighing sample

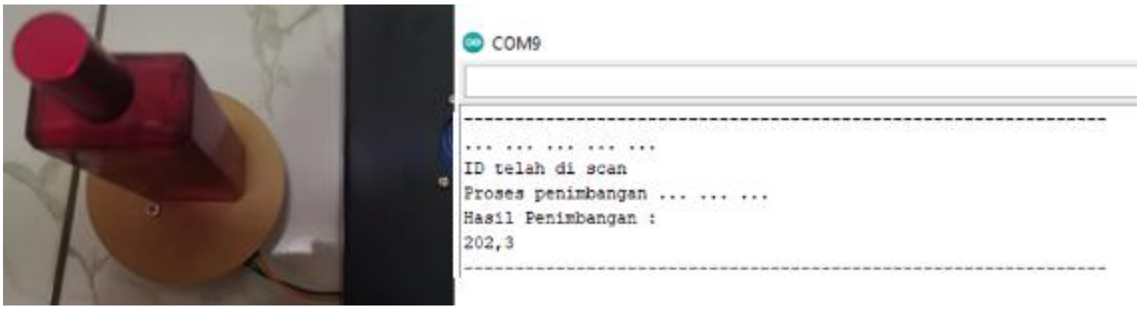

Figure 8 loadcell sensor reading of sample weight 1

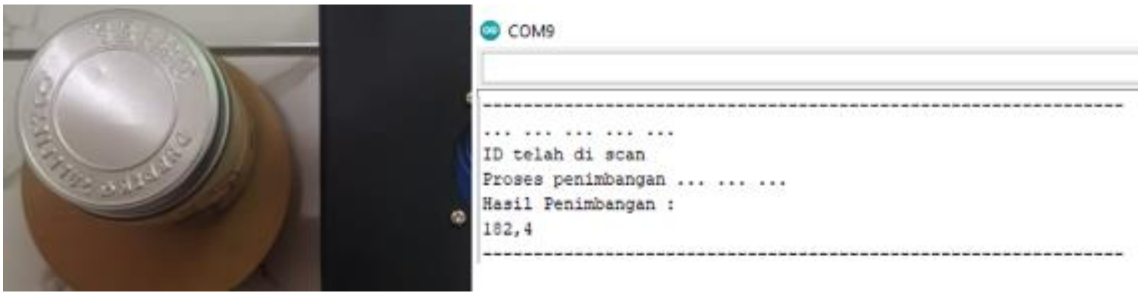

Figure 9 loadcell sensor reading of sample weight 2

Figure 10 loadcell sensor reading of sample weight 3

Table 6 Data comparison between loadcell and conventional scales

No	Loadcell reading	Conventional weighing	Weight difference	Error percentage
1	202,3 g	203,8 g	1,5 g	0,7%
2	182,4 g	183,5 g	1,1 g	0,6%
3	149,7 g	150,4 g	0,7 g	0,5%

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Based on table 6, it is known that through 3 weighing comparisons there is an error range from 0,5% – 0,7% where this error is still within the weighing error tolerance limit.

3.3. Scada HMI Functional Testing

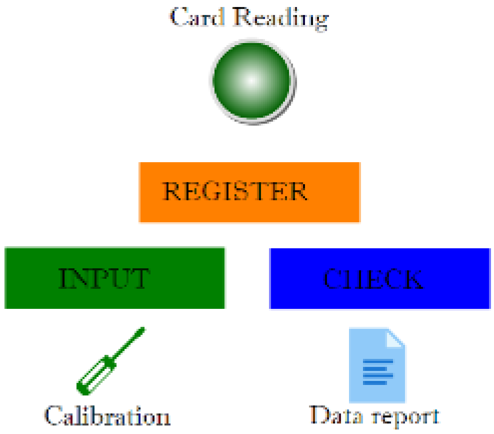

Figure 11 interface HMI Main page

Figure 7 shows the main interface (Main Page) on the Haiwell SCADA HMI, which serves as the operational control center for the truck data collection system. On this page, there is a Card Reading indicator that provides visual feedback during the RFID scanning process. System navigation is divided into three main functions: the REGISTER button for registering new identities, the INPUT button for the load data retrieval process, and the CHECK button for reviewing data status. In addition, there is a Calibration menu that directs users to the Smart Calibration configuration page to ensure load accuracy.

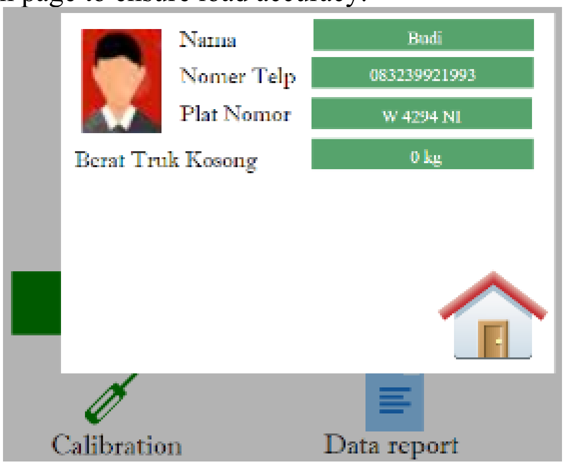

Figure 12 Interface Register page

Figure 8 displays the registration page interface used by operators to input initial driver data before entering the warehouse area. This page integrates personal identification data such as name, telephone number, and vehicle license plate number with the unique RFID card identity. An Empty Truck Weight parameter serves as the initial reference data to facilitate the calculation of net load weight during the final weighing stage. All information entered on this page will be saved in the system database to ensure data synchronization during the loading and unloading process.

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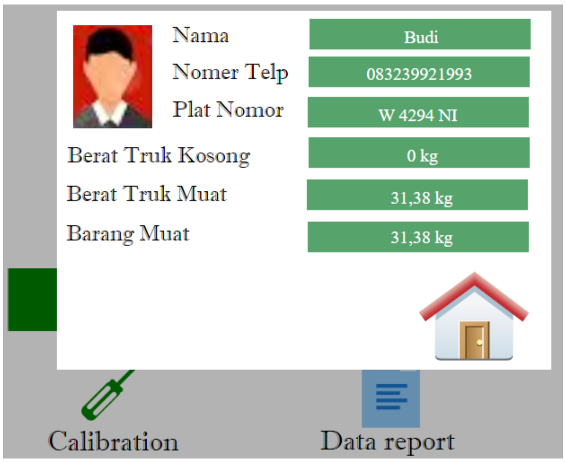

Figure 13 Interface Input page

Figure 9 displays the data input page that serves as an interface during the cargo input process. This page automatically displays the driver and vehicle identities based on the results of the RFID card scan from the previous registration data. Three weight parameters are processed in real-time: Empty Truck Weight (initial reference data), Loaded Truck Weight (load cell sensor readings after being calibrated using the smart calibration method), and Loaded Goods. The system automatically calculates the difference between the loaded truck weight and the empty truck weight to accurately obtain the Netto value or net weight of the loaded goods. This integration minimizes manual input errors and speeds up the loading and unloading administration process.

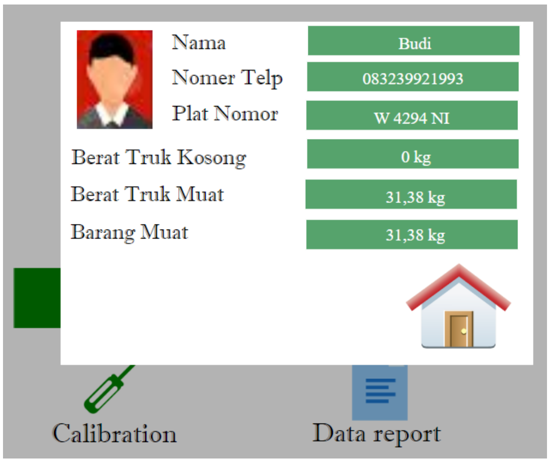

Figure 14 Interface Check page

Figure 10 shows the Check page of the HMI display of the device the researcher created. This page is where the driver confirms to the destination warehouse operator what goods are being

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loaded and will be unloaded at the destination warehouse. The operator then checks the loaded goods.

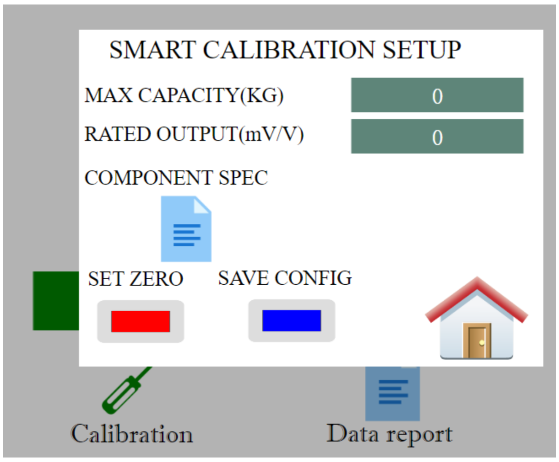

Figure 15 Calibration page

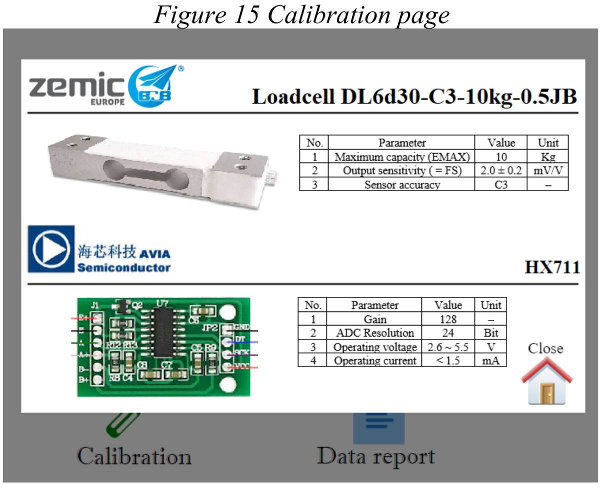

Figure 16 Specification page

Figure 11 shows the load cell sensor calibration page from the HMI display of the device the researcher built. The system operation procedure is carried out through the Smart Calibration Setup interface on Haiwell SCADA in the following order:

- The user presses the MAX CAPACITY (KG) field on the HMI screen until a virtual keypad appears, then enters the maximum sensor capacity value according to the device specifications (e.g., 10 kg).
- The user then presses the RATED OUTPUT (mV/V) field to enter the sensor sensitivity value. If the user has difficulty or is unsure of the sensitivity value to enter, they can press the document icon in the COMPONENT SPEC section. This button will direct them to the component specification page (figure 11), which contains detailed information and the Rated Output value of the load cell used as a reference for charging.
- The user then presses the SET ZERO button while the scale is empty. This function performs a tare operation to ensure that the weight of the device's mechanical structure does not affect the measurement results.
- Once all parameters are entered correctly, the user presses the SAVE CONFIG button. The system will automatically save the data to memory and update the Calibration Factor in the ESP32 algorithm.
- Once completed, the user can press the Home icon to return to the main display.

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Table 7 interface test data summary

Page	No	Scenarios test	Expected result	Status
Home	1	Pressing the navigation button between menus	Moves to the selected page without delay	Pass
	2	RFID card reading status indicator	Green light illuminates when RFID is read	Pass
Register	3	New RFID card registration	Card ID stored in system memory	Pass
	4	Double data validation	System rejects if card is already registered	Pass
Input	5	Load data input	Numerical data stored in database	Pass
	6	Real-time weight reading	Weight changes when load is placed	Pass
Calibration	7	Input mV/V (Smart Cal) value	System automatically changes scale factor	Pass
	8	Zeroing (Tare) function execution	Scale shows 0.00 kg.	Pass
Check	9	Cargo checking at destination warehouse	Displays data according to name, cargo, and driver's license plate	Pass

4. CONCLUSION

Based on the design and development of RFID-based Truck Loading Data Recorder Device, it can be concluded that this system effectively integrates weight measurement and driver identification. Experimental results show that the RFID sensor operates optimally within the range of 0 – 2 cm, with card alignment being a critical factor for successful data transmission. For the load cell system based on table 6, it is known that through 3 weighing comparisons there is an error range of 0.5% – 0.7% where this error is due to the influence of environmental noise (such as mechanical vibrations and micro-volt electrical signal fluctuations) which distort the Signal-to-Noise (SNR) ratio, thus triggering small fluctuations in the final load cell reading results. The effectiveness of the tool configuration time is significantly increased through the integration of the smart calibration algorithm. The calibration process which originally took 15 to 30 minutes in conventional methods, was successfully reduced to less than 1 minute (time efficiency reaching more than 95%). However, the data synchronization feature to the SCADA Cloud remains the subject of future work to improve remote monitoring capabilities and optimize communication protocols to ensure stable long-distance data transmission.While the primary goal of securing and digitizing loading documents has been achieved, this study identified the need for further optimization of the Cloud SCADA synchronization to enhance real-time remote monitoring.

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