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Original Research Article

Transforming weight measurement: a cutting-edge IoT-enabled smart weight machine for centralized price control of products

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ABSTRACT

Background: With the rapid advancement of machine learning technology, there is a growing interest in integrating it into IoT systems for enhanced functionality. In this study, we propose a SMART Weight Machine system designed to detect, weigh, and price various objects using machine learning techniques.
Methods: Our system utilizes TensorFlow, a machine learning framework, in conjunction with Raspberry Pi for object recognition. Image processing is performed locally on the Raspberry Pi for efficient detection. The system also incorporates MySQL for database management and a WebApp developed using PHP and Laravel for the user interface.
Results: Through our implementation, we achieved significant improvements in speed and accuracy. TensorFlow's compatibility with microcontroller devices like Raspberry Pi enabled swift processing, resulting in a 96% accuracy rate for object detection during our evaluation.
Conclusions: The SMART Weight Machine system demonstrates promising potential for real-world applications. Moving forward, rigorous testing and quality assurance will be conducted to ensure the reliability and accuracy of the system during the development phase.

Keywords: Raspberry-Pi, SMART weight machine, TensorFlow, WebApp developed using PHP

INTRODUCTION

Weight measurement devices, commonly known as weight machines, have played an integral role in various domains throughout history. From ancient times to the present day, scales have been utilized for a multitude of purposes, ranging from measuring commodities in marketplaces to weighing spacecraft in modern engineering.[1] The evolution of scales reflects the advancements in technology, transitioning from rudimentary balance scales to sophisticated digital equipment.[2]

The fundamental principle of a balance scale, dating back to Roman times, involves the comparison of an object's weight to a known reference weight.[3] This comparison ensures accuracy, a crucial aspect of weight measurement. Calibration, the process of adjusting a scale to ensure accuracy, has been a cornerstone practice across diverse societies.[4] Over time, standardization of calibration techniques and weights emerged as a necessity for uniformity in measurement systems worldwide.[5]

In contemporary times, the integration of machine learning technology has revolutionized traditional weight machines, giving rise to SMART weight machines.[6] Unlike conventional scales, SMART weight machines not only determine the weight of an object but also employ advanced algorithms for product detection and price selection from a database.[7] This innovation enhances efficiency and accuracy, catering to the

evolving demands of modern industries, particularly in retail settings.[8]

The capabilities of SMART weight machines extend beyond mere weight measurement. They possess the ability to detect products and autonomously retrieve pricing information, streamlining the transaction process.[9] This integration of technology not only improves operational efficiency but also enhances the overall user experience.[10]

In this paper, we present a comprehensive exploration of SMART weight machines, delving into their functionalities, underlying technologies, and potential applications. Through empirical analysis and case studies, we aim to elucidate the significance of these innovative devices in contemporary settings, highlighting their role in transforming conventional weight measurement practices.

In the field of weight measurement and smart scales, several noteworthy advancements have been made, showcasing the integration of innovative technologies to enhance accuracy, productivity, and functionality.

The Vision Smart Scale, as introduced by, represents a significant leap in weighing technology, particularly in the context of picking and packing applications.[11] By leveraging smart algorithms that combine weighing with visual recognition and picture capture, this scale ensures easy handling and error-free operation. Its seamless integration with production and ERP systems facilitates full data visibility and provides visual proof of successful order fulfilment, contributing to enhanced productivity and process traceability.

Fitzgerald et al present a ground-breaking solution for remote beehive monitoring through the development of a smart weighing scale.[12] This innovative scale accurately determines the weight of beehives, offering valuable insights into colony health and behaviour. Leveraging load cell platform weighing scale systems enabled with WSN technology and ultra-accurate analog-to-digital converters, this solution ensures precise weight data collection. Moreover, by incorporating temperature and humidity sensing nodes, the system compensates for drift errors, further enhancing measurement accuracy.

In their study, focus on the design and implementation of an IoT-based smart weight measurement machine, comparing it with conventional weight machines.[13] Utilizing weight sensors, load cells, and microcontrollers, this smart scale sends measured data to a web server for analysis and monitoring. The seamless hardware integration and data transmission highlight the potential of IoT technology in enhancing weight measurement accuracy and data accessibility.

Chandan et al introduce a novel approach to streamline the shopping experience through the development of a smart shopping trolley using Raspberry Pi.[14] This innovative system automates the billing process by generating bills in real-time as customers scan and add products to their trolleys. By eliminating the need for traditional checkout counters, this solution reduces waiting times and enhances overall shopping efficiency.

In a similar vein, Abhishek et al propose an automated shopping trolley system aimed at optimizing the billing process in supermarkets.[15] By empowering customers to self-scan products and generate bills, this system eliminates long queues at checkout counters, resulting in a more seamless and efficient shopping experience.

The course offered by Duke University provides valuable insights into the foundational concepts of machine learning and its diverse applications across various industries.[16] Through a combination of theoretical knowledge and practical exercises, participants gain a comprehensive understanding of machine learning models and their potential to solve complex problems in fields such as medical diagnostics, image recognition, and natural language processing.

Erratic fluctuations in commodity prices cause distress among consumers and challenges for policymakers in many countries, including ours. Prices often spike arbitrarily due to factors like religious occasions, national events, or budget announcements, exacerbating economic instability and straining household budgets. To address this, we developed a SMART Weight Machine with advanced functionalities. Our motivation is to combat price volatility and empower consumers and policymakers with a tool for price control and transparency. By integrating advanced technology, our SMART Weight Machine detects objects, measures weight precisely, and retrieves real-time pricing information from government databases, aiming to curb arbitrary price hikes and ensure accountability. Our vision is to foster a fair marketplace where goods' prices reflect their intrinsic value, not arbitrary fluctuations. By equipping shop owners with accurate weighing tools and preventing unauthorized price changes, our SMART Weight Machine promotes pricing integrity and consumer trust, heralding a new era of transparency and accountability in retail practices.

Overall, these studies underscore the significant strides made in the field of weight measurement and smart scales, showcasing the potential of innovative technologies to enhance efficiency, accuracy, and user experience across diverse applications.

METHODS

This study focuses on developing and analysing an IoT-enabled smart weight measurement system for centralized price control of products. Conducted over 11 months (May 2023 to March 2024), the research encompassed system design, prototype development, testing, and

performance evaluation in various scenarios to ensure accuracy and reliability. The research was carried out in the Department of Electrical and Electronic Engineering (EEE) laboratory at Premier University, Chittagong, which provided the necessary facilities and environment for the project's execution.

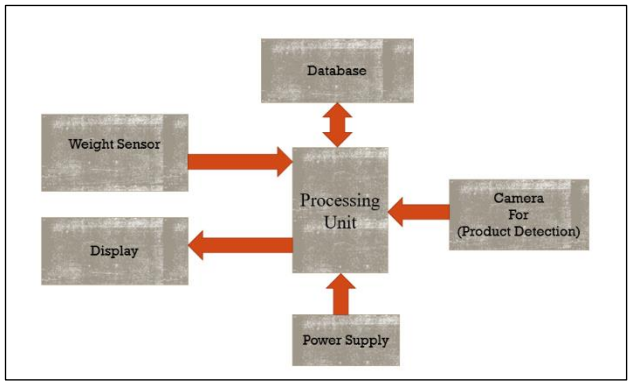

Figure 1: Block diagram of the proposed system.

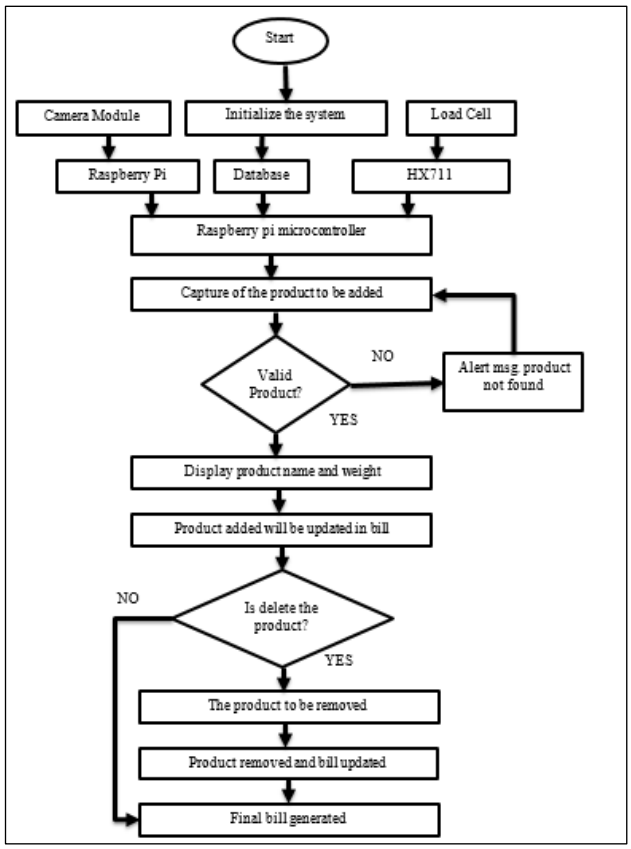

Figure 2: Flow chart of the designed system.

Figure 1 shows the SMART Weight Machine setup, where the process begins with a Raspberry Pi camera module capturing an image of the product and a sensor measuring its weight. The Raspberry Pi uses TensorFlow to analyze the image and identify the product, querying a database for relevant product information, including prices. This data is then displayed on an interactive interface, providing users with clear information about the product and its price.

Figure 2 continues the operational flow post-hardware initialization. The system verifies the product's validity, displays the product's name and weight, and dynamically updates the bill as products are added or removed. Upon checkout, the system generates a comprehensive invoice, offering a seamless solution for product identification, pricing, and transaction management.

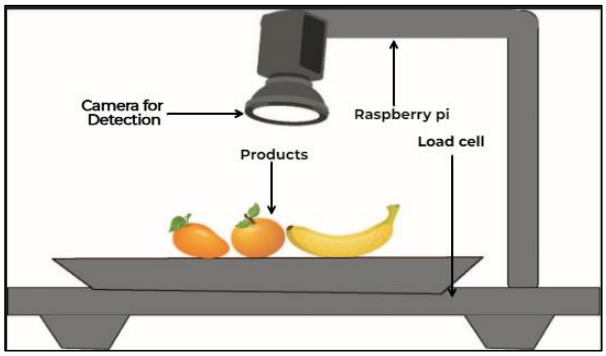

Figure 3: 3D mechanical design of smart weight machine.

Figure 3 details the process as a product is placed on the load cell of the smart weight machine. The load cell produces an analog voltage signal corresponding to the weight, which the HX711 analog-to-digital converter (ADC) converts into a digital value. Simultaneously, the Raspberry Pi camera captures an image of the product. The load cell's connections to the HX711 and the HX711's connections to the Raspberry Pi's GPIO pins enable accurate analog-to-digital conversion and data transmission for further processing.

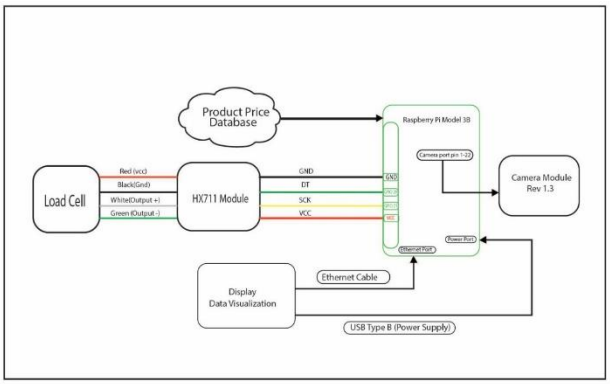

Figure 4: Schematic diagram of SMART weight machine.

Figure 4 illustrates the circuit diagram, depicting the hardware connections between the load cell, HX711 module, and Raspberry Pi, ensuring proper signal transmission and communication for weight measurement and image capture.

The sample prototype with the experimental setup is shown in Figure 5.

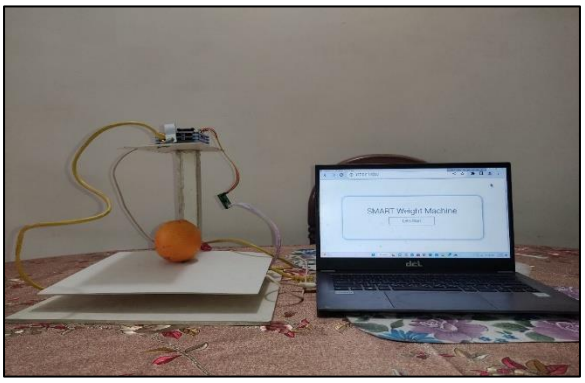

Figure 5: Experimental setup of SMART weight machine.

Working steps

To streamline user interaction and facilitate seamless transactions, a web application was developed using the PHP Laravel framework to connect users with the Smart Weight Machine. Upon accessing the app, users receive a unique link to connect to the machine.

Calibration: The system starts with calibration to ensure accurate weight measurements. Users can use "Calibrate" and "DE Calibrate" buttons on the web interface, placing a known weight on the machine for precise calibration.

Measurement Interface: When users click "Measure," the Raspberry Pi's camera captures an image, and TensorFlow processes it. The product name and weight are displayed on the interface (Figure 6).

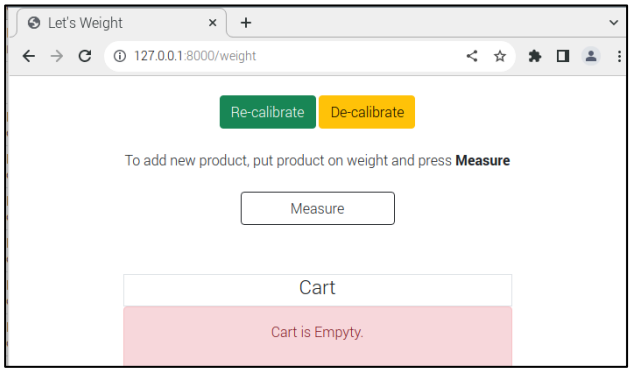

Figure 6: Ready to measure interface.

Adding products: Detected products, like "Product 01 - Apple" or "Product 02 - Carrot," can be added to the virtual cart by clicking "Add to Cart" (Figure 7).

Checkout interface: After selecting products, users proceed to checkout, where an invoice summarizes the cart's contents, quantities, prices, and total amount (Figure 8).

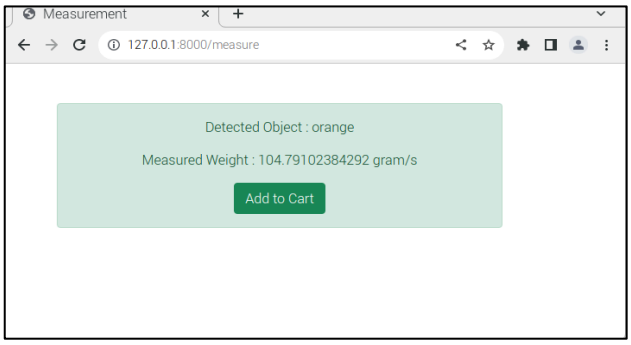

Figure 7: Product detection & add to card interface.

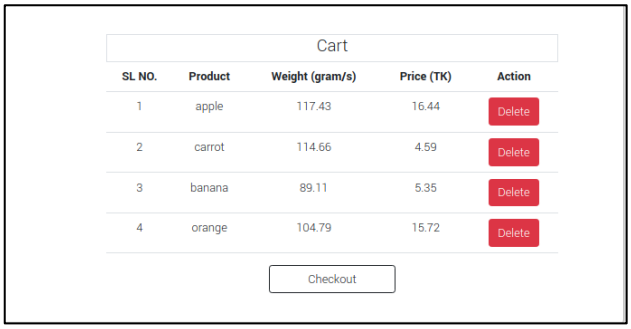

Figure 8: Product card ready to checkout interface.

Invoice generation: Selecting "Print Invoice" generates a PDF invoice with a detailed breakdown of products and prices (Figure 9).

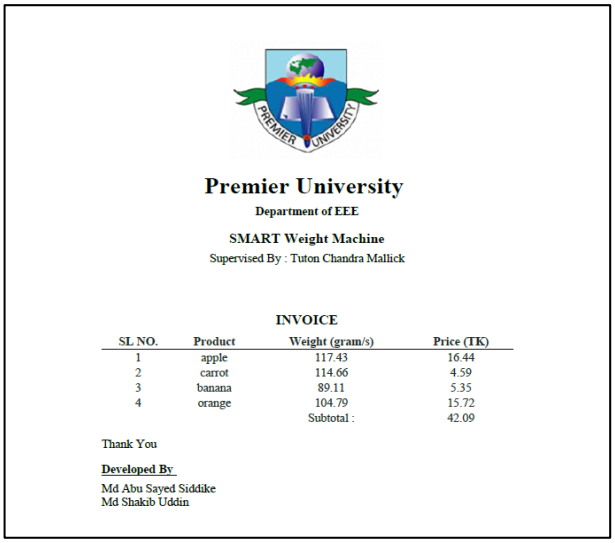

Figure 9: Sample invoice.

This systematic process ensures a user-friendly experience from calibration to checkout, enhancing efficiency and transparency in transactions.

RESULTS

The comparison between the standard weight machine and the SMART weight machine across 50 data points reveals consistent trends in deviation error shown in Table 1 (Sample 10 Data shown in table). Notably, the SMART weight machine consistently registers slightly higher weights compared to the standard weight machine, resulting in negative deviation errors.

Table 1: Compare product weight between standard weight machine and SMART weight machine.

SL No./product	Product Detection	Weight in standard weight machine (in gram)	Weight in SMART weight machine (in gram)	Deviation (error) (in gram)	Percentage error in 100%
1. Orange	Detected	103.21	106.47	-3.26	3.15
2. Banana	Detected	95.85	98.61	-2.76	2.87
3. Orange	Detected	101.59	104.79	-3.2	3.14
4. Banana	Detected	86.79	89.11	-2.32	2.67
5. Carrot	Detected	111.78	114.66	-2.88	2.57
6. Apple	Detected	115.27	117.43	-2.16	1.87
7. Carrot	Detected	86.78	89.11	-2.33	2.68
8. Apple	Detected	101.37	104.79	-3.42	3.37
9. Banana	Detected	78	80.23	-2.23	2.78
10. Orange	Detected	105	109.8	-4.8	4.37

Across various products, such as oranges, bananas, carrots, and apples, this deviation error remains relatively consistent, ranging from -2.16 grams to -3.42 grams. Percentage errors, calculated based on 100% of the standard weight, range from 1.87% to 3.37%.

This systematic deviation indicates a consistent bias in weight measurement by the SMART weight machine, with a tendency to overestimate weights compared to the standard machine. While the deviation errors are relatively small, they highlight the importance of calibration and validation processes to ensure accuracy in weight measurement applications.

Further investigation into the calibration methods and potential sources of bias in the SMART weight machine may be warranted to mitigate these deviations and enhance overall measurement precision.

DISCUSSION

The introduction of the SMART Weight Machine represents a significant advancement in retail technology, promising to revolutionize the shopping experience by automating product recognition and streamlining invoicing processes. By eliminating manual product entry and reducing checkout time, this innovation not only saves time but also enhances accuracy, ultimately improving overall customer satisfaction.[17]

However, certain limitations must be acknowledged and addressed. The machine's inability to support unrecognized products or those not yet added to the database could lead to confusion among customers, impacting their shopping experience negatively.[18] Additionally, the project's performance may be compromised under low-light conditions, resulting in reduced detection and recognition accuracy and slower processing times.[19]

Despite these challenges, if the government approves this proposal, widespread adoption of the SMART Weight Machine could offer a solution to inconsistencies in pricing and unfair trade practices. Mandating the use of this machine by all retailers would ensure standardized pricing based on the government's database, mitigating the influence of hoarders and dishonest traders and promoting fair and transparent commerce across the country.[20]

Limitations

One significant limitation of the SMART Weight Machine is its lack of support for unrecognized products. If the machine fails to recognize a product or if a new product is introduced to the market and not yet added to the database, it may not be possible to provide pricing information for these items. This can lead to customer confusion and negatively impact their shopping experience.

Another notable limitation is the machine's performance under low-light conditions. Reduced lighting can affect the detection and recognition accuracy of the machine, causing slower processing times. The algorithms and processes may require additional time to analyze data accurately in such environments, potentially diminishing the efficiency of the system.

CONCLUSION

The SMART Weight Machine, with its automated product recognition and invoicing capabilities, is poised to revolutionize the shopping experience by eliminating

manual product entry and significantly reducing checkout time. This project represents a substantial advancement in retail technology, offering a powerful and user-friendly solution that saves time, improves accuracy, and enhances overall customer satisfaction.

Approval of this proposal by the government will address inconsistencies in pricing and promote liquidity in our economy. Mandating the use of the SMART Weight Machine for all retailers will ensure that products are accurately weighed and detected, with prices determined based on the government's database. This initiative will protect consumers from hoarders and dishonest traders, fostering a fair and transparent marketplace.

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