Internet of Things based Smart Shelves Prototype Implementation

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Abstract—From customers' point of view, out-of-stocks occurs when a product is unavailable or not shelved in the expected location and this can cause the customers to either switch to another brand or retailers. When facing out-of-stock, customers will eventually stop substituting the product with another product. The customer will instead go to another retailer to satisfy his needs. This behavior has a negative impact on retailers, since retailers will lose a full shopping basket, and potentially the customer. This study provides a proof-of-concept of smart shelves system that is equipped with force-sensitive resistors, Raspberry Pi and the Arduino microcontroller. The system is able to monitor all stocked items and send item status updates to mobile phones/electronic devices when items become sold out. The prototype undergoes interoperability test, compatibility test and functionality test to ensure the hardware and software are able to function according to the requirements. The overall results show that the prototype is able to measure the monitored items and transmit the data to the mobile application in real time. The prototype presented in this study may facilitate the development of smart shelves solution using IoT technologies in the retail environment. An expansion of this prototype in the retail environment can have an impact in both retails and supply chains when on-shelf inventory can be collected automatically and efficiently.

Index Terms—IoT, out-of-stocks, smart shelves, retail.

I. Introduction

Internet of Things (IoT) can be described as connecting everyday objects such as smart phones, sensors and actuators to the Internet where the devices are intelligently linked together to enable new forms of communication amongst people and themselves. The significant progression of IoTs over the last decades has created a new dimension to the world of information and communication technologies. Although there is no formal definition of IoT, a number of standardization bodies have outlined descriptions of IoT. In [1], the Internet Engineering Task Force (IETF) gave the following description of IoT:

> "The basic idea is that IoT will connect objects around us (electronic, electrical, non-electrical) to provide seamless communication and contextual services provided by them. Development of RFID tags, sensors, actuators, mobile phones make it possible to materialize IoT which interact and co-operate each other to make the service better and accessible anytime, from anywhere."

In [2], the Internet Society give the following description:

> "The term Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention. There is, however, no single, universal definition."

The innovation of IoT offers multiple opportunities in agriculture, manufacturing, production and retail industries by increasing the availability of information along the value chain of production using networked sensors. IoT involves interfacing objects, sensors and actuators through the Internet and allowing them to communicate and exchange information between themselves to achieve intelligent and real time tracking, monitoring and management. The retail industry has been advancing over the last decade due to the impact of the information technology and this has led to adoption of different value-added propositions in terms of processes involved. Using IoT, retailers will not only be able to increase sales, enrich customer experience and manage store inventory effectively.

One of the most promising next-generation retail technology with IoT application is smart or intelligent shelves. Smart shelves are electronically connected shelves that automatically keep track of inventory in a retail store [3]. These shelves use a combination of sensors, digital displays and radio frequency identification (RFID) tags to provide detailed products usage, shopping patterns and sales data to retailers and manufacturers. Shelf-out-of-stock is one of the leading motivations of the smart shelves innovation [4]. Out-of-stock events occur when a product is unavailable on shelf for customer to purchase and can potentially has negative impacts on the retailers and manufacturers [5]. According to a report published by Efficient Consumer Response (ECR) Community [6], when the items of interest are not available on the shelves, 37% of the European consumers will switch to another brand and 21% of the European consumers are likely to switch to another store.

The main objective of this paper is to propose a proof-of-concept for a smart shelves system that allows user to track the items in the shelves. The concept behind the Smart Shelves system is to use three force sensitive resistors for weight measurement. The force sensitive resistor changes its value when a force is applied to it which allows a user to know the weight of the item in the shelves. This information is made accessible through a smartphone application that is linked through a wireless connection made available by the Raspberry Pi. Essentially, the system allows the user to always have an updated inventory of the items stored in the shelves.

II. Background of the Study

To address the issue of out-of-stock, researchers have come up with several solutions [4], [7]–[9]. In [7], the authors proposed a solution that combines IoT and image processing to improve on-shelf availability. In the proposed system, the authors implemented load sensors on shelves of retailers that can measure the weight of the items. However, the authors found that the data became unreliable when the customers put incorrect items on the shelves. Therefore, the authors used image processing to find out how much shelf space a product is occupying or if the product is in the correct shelf. Nevertheless, the system is unable to process the images correctly if the products are not properly displayed or if the logo or the brand of the products is not visible in the images.

The authors in [4], [8] implemented an embedded sensor network which consists of distributed autonomous sensors controller with a radio frequency (RF) transmitter to track the shelf behavior in real-time. The data from the sensors is managed by a web-based shelves management system, which is accessible from anywhere and hosted on a cloud. The hardware system has been patented [10] worldwide and installed to a number of different retail stores [4], [8]. The hardware system implementation is intended to evaluate the feasibility of monitoring item availability at retail stores and acquiring the inventory level of examined products. The system has gone through an 18-month of stress tests for real-time data acquisition and transmission.

III. Experiment Environment

A. System Flowchart and Architecture

The system consists of a mobile application developed using the Android platform and an Arduino that is connected to Raspberry Ethernet based cloud server. The Arduino microcontroller and Raspberry Pi are the main controllers that hosts the cloud server and performs the necessary actions that needs to be carried out. The force-sensitive resistors (FSRs) are directly interfaced to the Arduino microcontroller. FSRs are sensors that able to detect physical pressure, compression and weight. They are basically a resistor that changes its resistive value (in ohms Ω) depending on how much it is pressed. Fig. 1 presents the flowchart of the Smart Shelves system. The system starts by reading the resistive value from the FSRs using the Arduino Uno. The Arduino calculates the weight of the item using the resistive value. The calculated weight is then sent to a cloud server.

The smart shelves can be monitored from a remote location using the Android application, which will communicate with the Cloud using web socket protocol via the Internet. Any Internet connection via Wi-Fi or 3G/4G network can be used on the user device. Node.js is used to implement web socket protocol in Raspberry Pi. A connection from Arduino to Raspberry Pi is needed in order to retrieve a weight reading of item via Android application. Fig. 2 is the system architecture for the Smart Shelves System.

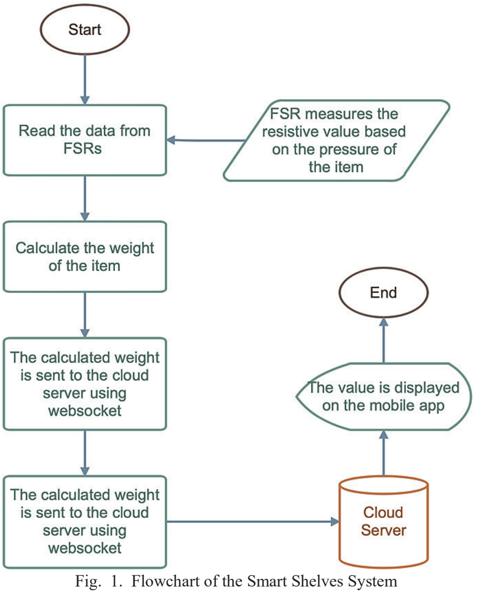

Fig. 1. Flowchart of the Smart Shelves System

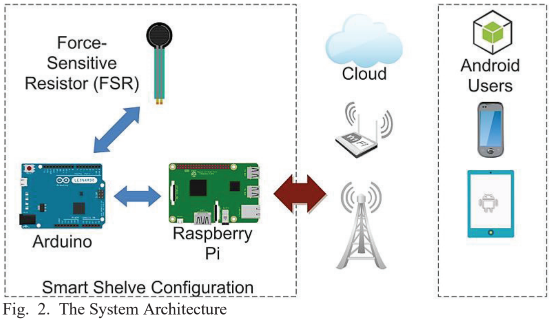

Fig. 2. The System Architecture

B. High Level Design

Fig. 3 shows the complete hardware schematic of the Arduino board and the FSRs. Fritzing software has been used to design the diagram shown in Fig. 2. The connection began with the FSR and Arduino Uno microcontroller. The Arduino Uno connects with Raspberry Pi, FSR and 10K resistor. Arduino calculates approximate weight of an item in the smart shelf with the help of FSR sensor. The Arduino Uno microcontroller programming has done by Arduino IDE and Raspberry Pi microcontroller programming has been done by Nodejs.

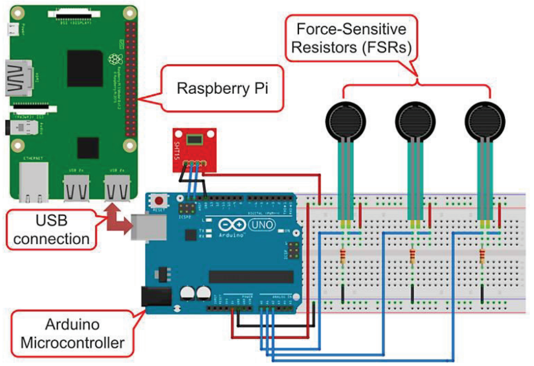

Fig. 3. Hardware schematic for the Arduino microcontroller and FSRs

Table 1 shows the specification of hardware and software that are used in this project. The Arduino microcontroller and Raspberry Pi are used as the main controller to this project. The application is developed in order to get an item weight reading and displayed to the Android users.

TABLE 1
HARDWARE AND SOFTWARE SPECIFICATION OF THE SMART SHELVES PROTOTYPE

Hardware/ Software	Specification
Arduino Uno	• Microcontroller: ATmega328 • Clock Speed: 16 MHz • Memory: 32 KB • Analog Input Pins: 6
Raspberry Pi 3	• Microcontroller: Model B • RAM: 1GB • 802.11.b/g/n Wireless LAN • Bluetooth 4.1
Force Sensitive Resistor	• 0.5" Diameter • Sense range: 100g010kg
Resistor 10k	• 1/6th Watt • +/0 5% tolerance PTH resistors
Arduino IDE Nodejs React Native	• Arduino Uno microcontroller programming. • WebSocket protocol in Raspberry pi. • Raspberry Pi microcontroller programming. • React Native Programming

C. Hardware Implementation

Fig. 4 presents the complete hardware implementation of the Arduino board, Raspberry Pi and the FSRs. The FSRs are attached to a breadboard and the wires are used to connect the FSRs from the breadboard to the Arduino Uno board pins. The breadboard allows power (voltage) to flow through from the laptop to the Arduino Uno and to the FSRs.

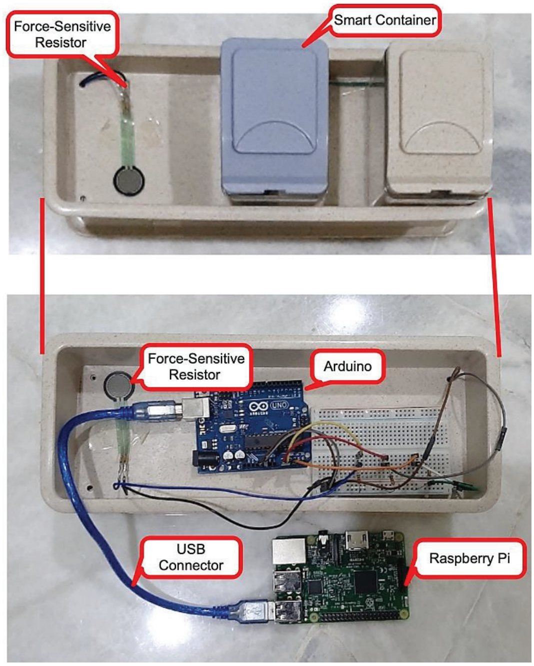

Fig. 4. Hardware implementation of the Smart Shelves prototype.

Arduino Uno is the middleware platform that use in this project. The data of the FSRs is sent to the Arduino Uno and being calculated by Raspberry Pi to be displayed in the mobile application. A USB connector cable is used as the medium between Raspberry Pi and Arduino Uno. The calculated data from the Raspberry Pi will be sent to the cloud database using the WebSocket protocol in order to display the data in mobile application.

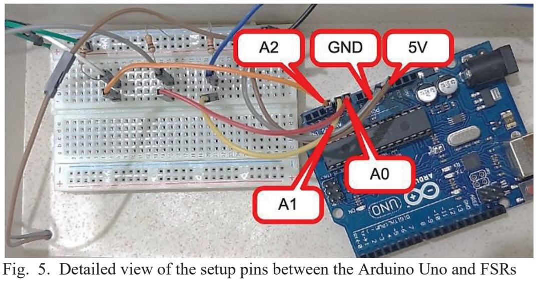

Fig. 5. Detailed view of the setup pins between the Arduino Uno and FSRs

Fig. 4 and 5 shows the connectivity of force sensitive resistor sensor and the Arduino Uno using the breadboard, jumper wire and 10k resistor in the Arduino Uno. The FSRs can detect the object by displaying result at Raspberry Pi terminal in gram with an accuracy point of two decimal place.

III. Prototype System Tests

This section describes the test strategies that are used for the proof-of-concept. The tests are used to ensure that the hardware and software can function according to the requirements.

A. Interoperability Test

The interoperability test is to make sure the different devices able to support the required functionality among themselves, other external devices and implementations.

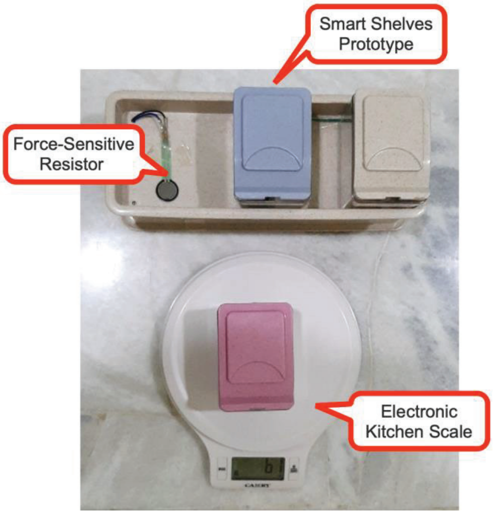

Fig. 6. Setup for the interoperability testing

For the interoperability test, the prototype is tested in a proper environment. Fig. 6 shows the setup for this test where the weight detected by the FSR will be compared against a normal electronic kitchen scale to see the FSR's accuracy. Different objects are used test the accuracy of the FSRs. In this test, the weight of each item is measured using an electronic scale before it is being measured by the prototype. Table 2 shows the measurement readings using both an electronic scale and FSRs of the prototype.

TABLE 2
ACCURACY TEST RESULT (IN GRAM)

1st Data Reading		2nd Data Reading		3rd Data Reading	
Scale	FSR sensor	Scale	FSR sensor	Scale	FSR sensor
200	200	200	199	200	200
400	400	400	400	400	399
600	600	600	598	600	600

B. COMPATIBILITY TEST

In the combability test, the IoT product is tested with multiple configurations, protocol versions, product versions, forward and backward compatibility, mobile devices and OS. For the Smart Shelves prototype, the mobile application (shown in Fig. 6) is tested in three different Android platforms. The test is important to see the functionality of the application in different Android platforms and its suitability for the devices. The testing results are shown below in Table 3.

TABLE 3
COMPATIBILITY TEST FOR DIFFERENT VERSION OF ANDROID

	Button Functionality			
DEVICE	BACK	HOME	UPDATE	INFO
ANDROID 3.0 Honeycomb	FAIL	FAIL	FAIL	FAIL
ANDROID 6.0 Marshmallow	PASS	PASS	PASS	PASS
ANDROID 9.0 Pie	PASS	PASS	PASS	PASS

From the combability test result, it is concluded that the mobile application is only compatible with android platform 4.0 and above because of certain features that required latest API which is missing for android platform below 4.0.

C. USABILITY/USER EXPERIENCE TEST

This test is the process of watching or tracking an actual user while they use product to see if it's in fact usable. Usability testing is the best way to understand how real users experience application. The test looks at the ability to recognize functionality and how to use it is very crucial for any consumer products. Fig. 7 presents the Android application for the Smart Shelves prototype that is used in the usability test.

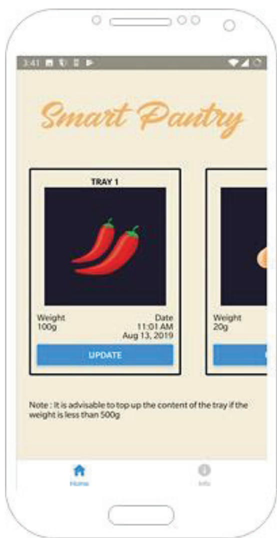

Fig. 7. Android application for the Smart Shelves prototype

In this test, the developer explained about the task cases that the participants should complete. Each test case is described in Table 4 under the task name and each task is represented with a task code T0xx, which "T" is the abbreviation of Task and "xx" is the abbreviation of the task numbering. The test cases table of Smart Shelves prototype is explained on Table 4.

TABLE 4
USER TEST CASES

Task Code	Task Name
T001	Let's start
T002	Tracking weight data of tray 1
T003	Tracking weight data of tray 2
T004	Tracking weight data of tray 3
T005	Exit

Table 5 shows the result data in the form of participant's tasks completion and their tasks completion time. The high values in the task completion time for T002 indicates that the participants require some time to familiarize themselves with the application interface and the hardware environment right after T001, which is after the application has started. After the participants has familiarize themselves with the application interface and the hardware environment, the task completion time begin to decrease, as shown by the data for T003 and T004 in Table 5.

TABLE 5
TASK COMPLETION TIME (IN SECONDS)

Participant	T001	T002	T003	T004	T005
A	3	12	8	6	3
B	5	14	7	7	2
C	2	15	9	7	3
D	3	13	10	8	2
E	4	14	6	5	2

1V. DISCUSSION

This study indicates that the prototype of the Smart Shelves system can provide a real time measurement and can be monitored using a mobile application. The results of the present study suggest that to develop a smart shelves prototype is quite straightforward using low cost hardware. This research can serve as a base for future enhancement in retail environment. By adding notification functionality in the mobile application, the system can increase products' availability and reduce lost sales due to out-of-stocks. Sensing out-of-stock and sending notification functionalities should be also combined with the retail inventory management in order to have more significant impact.

Furthermore, the system can create opportunities to the supply chains adding the ability to track products and their shipment information. The tracking information can give an understanding on the products movements and help retailers to make appropriate decisions to reduce the impact of delays, reduce fuel costs and increase in-store sales.

However, the main challenge in developing this system is to integrate different type of hardware to create a complete working prototype. The developer has to ensure that the hardware are compatible with each other and able to function as a complete system. In addition, the working prototype should be able to integrate and function with the rest of the current infrastructure of the retail inventory management system and the supply chain. The success of the prototype implementation also depends on whether the retailers are willing to upgrade their facilities.

Another challenge that should be noted is the security challenge. The developer needs to ensure that the transmission of the information through wireless connection is secured and impervious from any unauthorized interception. The consumer privacy also needs to be considered if the product tracking includes the use of the consumer information.

V. CONCLUSION

The purpose of the current study to implement a proof-of-concept for a smart shelves system using IoT technology and evaluate the system in term of its interoperability, compatibility and usability. The smart shelves system can be hugely beneficial both for the customers' shopping experience and the retailers' selling experience. The proof-of-concept detects the object weight in the tray of smart pantry prototype by using force-sensitive resistor sensors. It also provides object weight reading in real-time that can be monitored by a mobile application. The measurement readings of the force-sensitive resistors in the interoperability test show 99% of accuracy which indicates that the resistors can be used as an alternative in detecting the monitored items availability. However, the prototype is not implemented in a real shelf environment, which can be realized as a future work. In addition, the Android application should not only monitor the current items, but also should provide a notification if the items are not available on the shelf to increase product availability.

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