Distributed RFID Shopping System

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ABSTRACT: *RFID technology has recently made significant advancements in the domain of retail sales. This paper presents a novel approach to the use of RFID technology in this field. Despite the current system architectures in RFID systems used in similar research projects, a distributed architecture and a suitable design are proposed. Users will be able to scan their purchased products by putting them in the shopping cart, view their current bill on the cart's touch screen, and get directions in the shopping area. The motivation behind this different approach is to give customers more flexibility and control over their shopping cart. It will enable them to benefit from information about the products and aisles of the shopping space. Additionally, it will also enable the storage of customer transactions and location data to render it available for data mining purposes.*

Keywords: RFID Shopping, RFID Tag, RFID Reader, Distributed Architecture, Indoor Positioning System

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1. Introduction

The Radio Frequency Identification (RFID) is a technology based on radio frequency communication between a number of tags and readers. It is increasingly used in many domains such as inventory management, supply chain management, retail sales and others.

A large body of work has been done on the application of the RFID technology in the enhancement of services in supermarkets and other shopping areas. The adopted approaches were mainly focused on the exit points in shopping areas. Those systems enable the customers to scan their shopping cart products by RFID readers at the exit of the supermarket and to generate the bill. Directions to specific aisles and areas, and discount information were also made possible. The waiting time in queues was significantly decreased, and the sales were smooth. However, the customer interaction with their bill was not tackled by those designs.

This paper's contribution to existing research is a distributed architecture for the RFID shopping system, where the scanning of products in a supermarket is performed at the level of each shopping cart. The customers can scan their purchased products by simply putting them in the shopping cart. They will also be able to see their current bill on the cart's touchscreen. The customers will have the choice to get directions in the shopping area, to be informed of their current location, and to set a threshold for the bill total. The motivation behind this different approach is to lower the cost on implementation of such systems and increase the ease of integration in existing points of sale.

This paper first presents the system's distributed architecture, followed by the mechatronic system main components. Next, a cost estimation of the system is given, and a conclusion is presented as closing.

2. System Architecture

The architecture of the system is based on a distributed model as shown in figure1. The scanning of the tags is not done at stationary points such as supermarket exits. Instead RFID readers are placed on each shopping cart to scan the RFID tags placed on each item. The shopping carts are also tracked by an Indoor Positioning System whose base point is located at the base. Composed of the transaction and the current location, the information is then sent to the base that serves in this case as an interface with a database where the data is stored permanently.

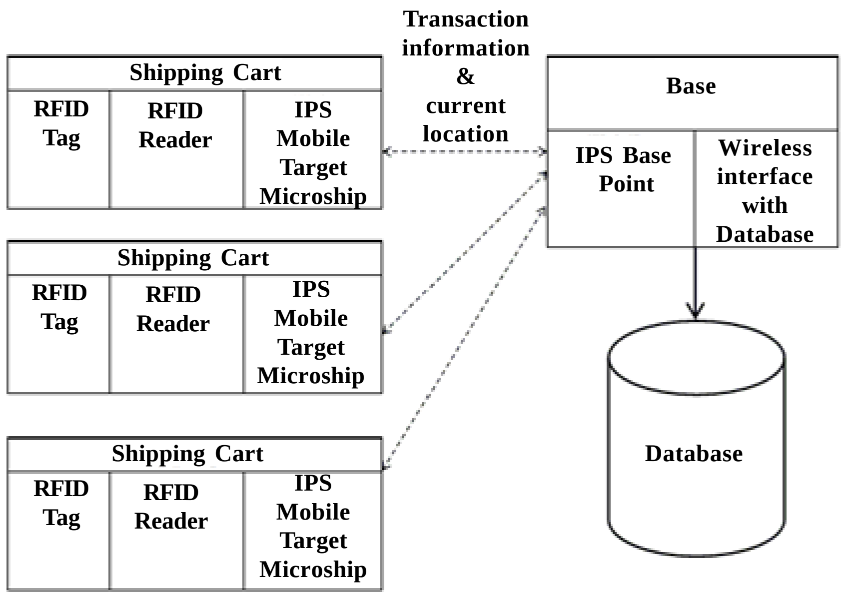

Figure 1. Distributed System Architecture

3. Mechatronic System Design

The design of the mechatronic system encompasses many components such as actuators, sensors, signal conditioning and interfacing unit, digital control unit, and graphical displays as shown in figure 2.

Sensors such as RFID readers and IPS base point sense the radio and ultrasonic wave signals from the environment, and deliver them to the signal conditioning and interfacing unit, which converts the input signals to digital ones. These latter are then processed by the Peripheral Interface Controller (PIC). The results of the processed signal are then displayed to the user using graphical displays such as resistive touch screens, and also given to actuators represented by the RFID tags and IPS mobile target microchip so that they can act on the environment by emitting radio and ultrasonic frequencies.

3.1 Sensors and Actuators

3.1.1 RFID System Design

RFID systems are generally made of a reader and a suitable tag. Tags are classified as passive or active. Passive tags do not require a power supply; the power is instead supplied by the RFID reader as shown in figure 3.

The reader is composed of a coil antenna, a capacitor Cr, a resistor Ri, an alternative current source, and a microchip for analog to digital conversion, modulation and demodulation. As for the tag, it is made of an antenna, capacitors Cr and Cp along with a tag memory containing the information to be communicated to the reader.

When the passive tag encounters radio waves emitted by the reader, a magnetic field is formed by the tag antenna. Power is then drawn from the reader by induction of potential in the tag antenna, supplying energy to the tag circuit. The tag then sends the

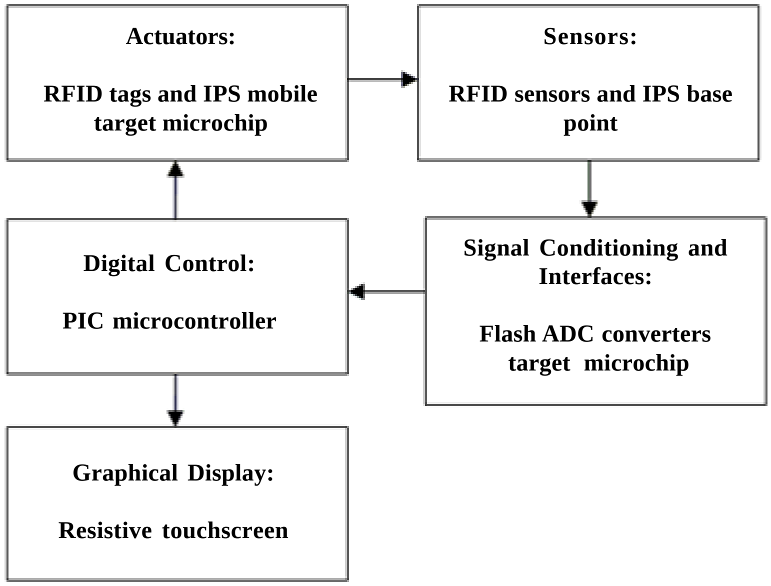

Figure 2. Mechatronic System Design

information encoded in its memory to the reader.

This specific application of the RFID technology requires the use of passive tags since they do not require a significant scanning range and have a small size compared to active ones.

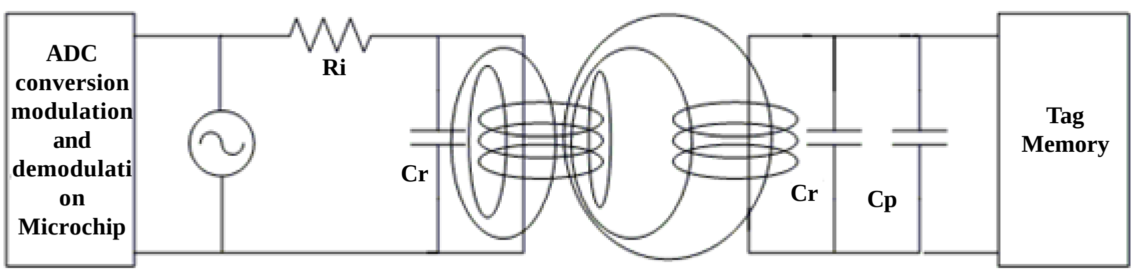

Figure 3. RFID tag and reader internal design

This circuit, figure 3, resonates at 13.56MHz which represents the operating frequency of this RFID system. Therefore the tag chip can get a maximum input voltage through this parallel resonant circuit.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$L = \frac{1}{(2\pi f)^2 C} \tag{2}$$

For the general case, according to equation (1), the resonant frequency of this parallel resonant circuit can be decided by the inductance of the tag coil antenna and the capacitance of capacitor Cr inside the tag. Then equation (1) can be transformed into equation (2) to find the corresponding inductance of the coil.

3.1.2 Indoor Positioning System (IPS)

Indoor positioning systems aim at estimating the current location coordinates of a traceable object based on the availability of wireless signals used for communication.

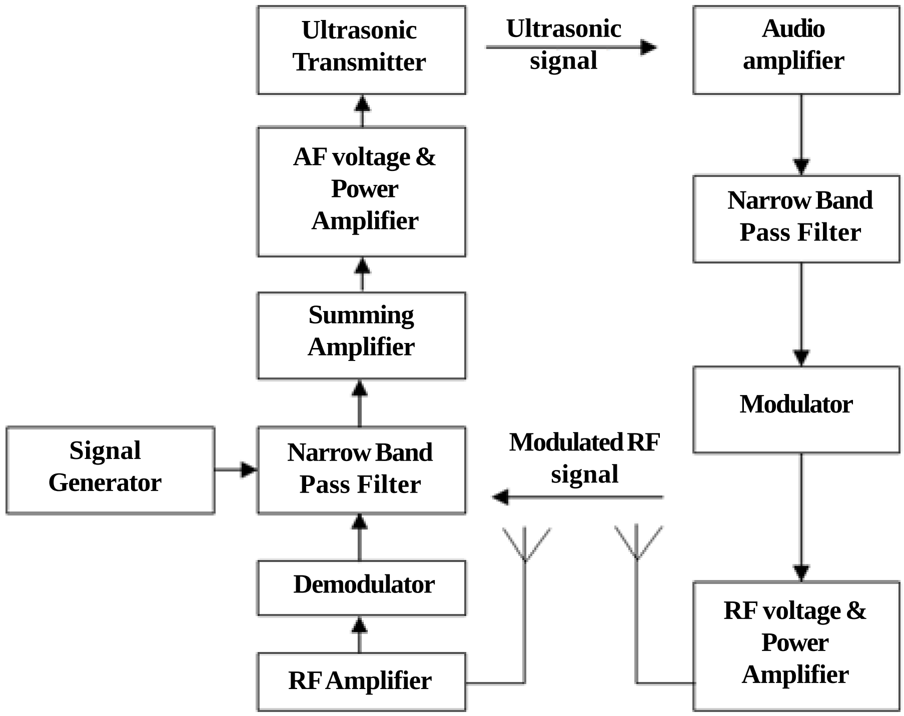

Figure 4. Indoor positioning System Components

Each shopping cart will be equipped by a wireless ultrasonic transmitter. The base point will be able to communicate with the Mobile target using ultrasonic signals and an antenna to receive the modulated radio frequency signal.

As figure 4 shows, the base point will send an ultrasonic signal to the mobile target receiver, which will be amplified, filtered, modulated, and amplified again using the RF and power amplifier to be ready to be sent by the antenna. The base point antenna will receive the RF signal sent by the mobile target, demodulate it, and filter it to render it available for processing. The process is then repeated at a constant rate, thus communicating with the mobile target continuously.

Based points will be deployed in a way to cover the entire area of the supermarket. The signals should be within reach at any location at the supermarket sales area. Concerning the location estimation, one of the methods used to realize it is triangulation.

This method uses geometric properties of triangles to estimate the target location. It has two derivations: lateration and angulation. Lateration estimates the position of an object by measuring its distances from multiple reference points. This latter is also called range measurement techniques. Instead of measuring the distance directly using received signal strengths (RSS), time of arrival (TOA) or time difference of arrival (TDOA) is usually measured, and the distance is derived by computing the attenuation of the emitted signal strength or by multiplying the radio signal velocity and the travel time. Besides, range estimation in some systems uses Roundtrip time of flight (RTOF). Angulation locates an object by computing angles relative to multiple reference points [1].

3.2 Signal Conditioning and Interfacing

3.2.1 Analog to Digital Converters

Analog-to-Digital converters or ADCs are considered as one of the most vital building blocks of an RFID system's operation. A wide range of ADCs exist and many are used according to the purpose and needs of their specific applications. For this application of RFID systems Flash ADCs are to be used. Flash ADCs are used in RFID tags and readers implementation thanks to their fast conversion [2].

As shown in figure 5, flash ADCs need many comparators. The comparator used in this circuit is mainly an amplifier without feedback. When the voltage has reached Vn1, the comparator linked to it is automatically lead to a high voltage output, triggering the LED to light by representing it as a digital output (0001). The same process will be followed by the other comparators until it reaches the digital output (1111).

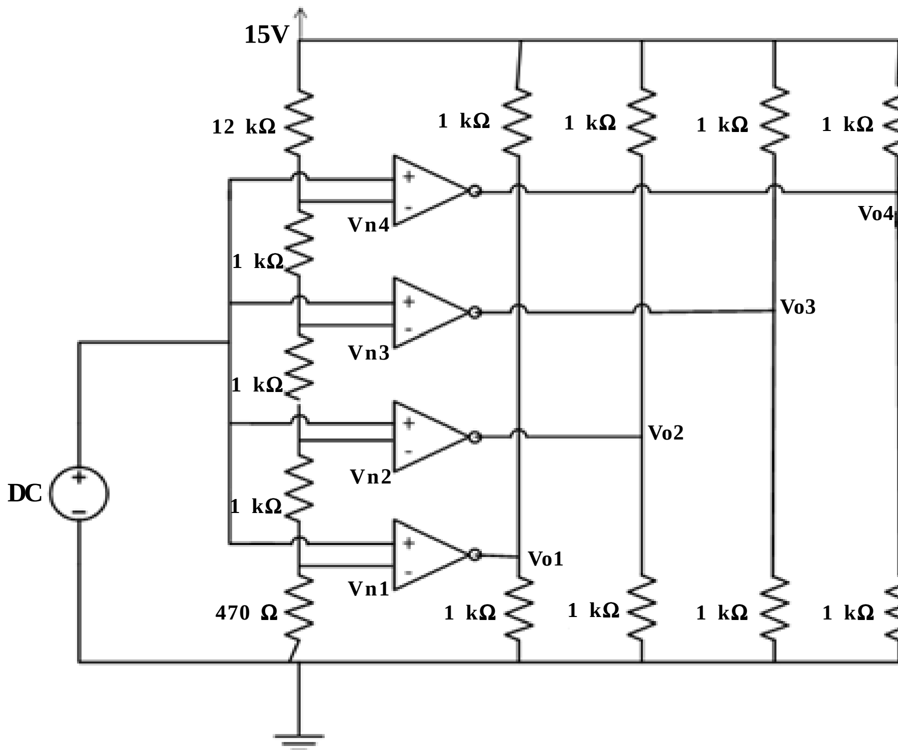

Figure 5. Flash ADC circuit

This is a very effective way of converting analog to digital signals since all the comparators work together which makes this conversion productively fast; that is the reason behind calling it a flash ADC. The 1kÙ resistors are used to keep the comparators' output voltages high.

3.3 Digital Control Architecture

3.3.1 Microcontrollers

A microcontroller is an embedded, special purpose computer that will be integrated in the system. Its main use is to perform all logic and arithmetic operations that are needed. In fact, the system's microcontroller is programmable and allows for the execution of all functionalities required such as setting the threshold as an input, addition and subtraction of prices, computing the total bill along with other functions that can be added and maintained as needed.

In general, the software that microcontrollers use is stored in a Read Only Memory that can have up to 1,000 bytes and 20 bytes of RAM for a typical low end microcontroller [3]. This memory space that these devices allow for will enable the system to store enough data entered by the user while shopping.

The system is to use a Peripheral Interface Controller (PIC) that provides many advantages. For instance, its speed is very distinguishable from other microcontrollers as it allows for the execution of 5 instructions per microsecond when operating at its maximum clock rate [4]. Furthermore, it has a simplified instruction set (only 35) [4]. It also allows for a robust protection system that ensures that the chip operates only when the voltage supplied meets the voltage specification and is reset if it is not functioning well [4]. Equally important, it is characterized by advanced programmable timer options that handle efficiently execution timing [4]. Furthermore, this device is equipped by a resilient output pin control that ensures driving output within a very small instruction execution time [4].

In addition to that, PIC is very easy to program through the use of a simple version of BASIC or flowcharts [5]. The PIC takes input from the touchscreen, which will be discussed in the upcoming section, and sends output signals to this latter in which results are to be displayed.

3.4 Graphical Displays

Graphical displays represent the system's interface with the user. The use of appropriate technology and the user friendliness on the graphical user interface are of great significance to the success of the system in case of deployment.

3.4.1 Resistive Touchscreen

This type of touchscreens uses two layers that are coated with a resistive and a conductive material. As shown in figure 6, these two layers are separated from each other by an air gap or spacers. On top of the whole mechanism will be a layer to provide resistance to scratches.

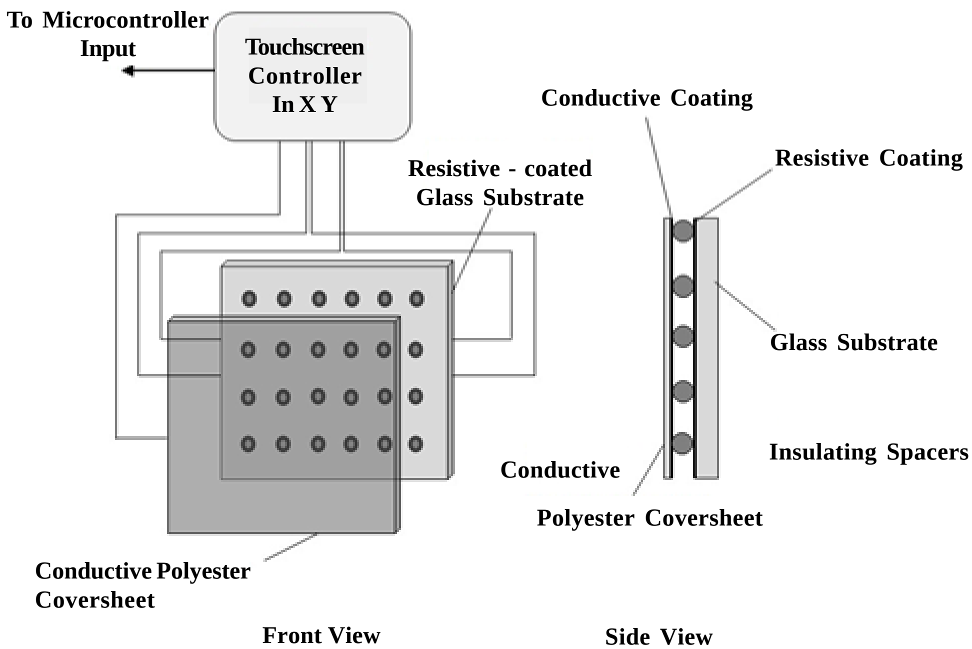

Figure 6. Resistive Touchscreen

The monitor of the display is made operational in nature. Thus, when our finger touches the screen, a contact is made between the two layers and current flows through them. As the layers make contact at the same point, the correct location of the point is noted.

The location is calculated by the computer in the course of change in the electric field occurred by our touch. Thus when the position is known, it is passed on to a driver in the device which codes it and sends it to the OS of the device.

4. Cost Analysis

The cost of passive tags depends on the frequency of operation, the amount of copper used in the tag antenna, the packaging of the tag, and the memory size. UHF tags generally cost less than high frequency tags. Passive RFID tags generally cost from 20 US cents to 40 US cents. The cost of the passive tags used is lower than that of active tags currently used in many shopping places where the scanning is done at the level of the exit [6].

The readers for passive RFID tags are also of low cost due to their design. The lowest prices on the market can go up to 100 US $.

Concerning the IPS used in this system, its design is of very low cost due to the technology it uses, which was presented earlier. The cost of this type of IPS is 15 US $ [7].

As for the Peripheral Interface Controller, it comes in different versions which differ in prices based on their pin-out configurations and memory capacity. For instance, there are the PIC10F200, PIC10F202, PIC10F204 and PIC10F206which are offered in 6-pin SOT-23 packages [8]. The prices of all these devices range between 0.49$ and 0.65$ which are of low cost and can be afforded by any business entity [8]. The PIC10F200 costs $0.49, for the PIC10F202 and PIC10F204 both cost $0.57 each, and the PIC10F206 costs $0.65 [8].Other microcontrollers may cost a little more based on their peripherals and pin configurations such as the 8-pin PIC12F629 that is available under a cost of $1.29, or the 20-pin PIC16F628 that costs about $3.35 [9]. Any of the previous PICs can be used in the implementation of the system as they are feasible and affordable.

The deployment of such system has also a cost that depends on the scale of the project. The area to be covered by the IPS and the number of shopping carts moving in it, directly affect the overall cost of deployment.

5. Conclusion

This paper presented a new approach to shopping using the RFID technology. The distributed architecture has many advantages which renders it a good alternative to current approaches. One of the advantages is the improved customer service, by giving the customers control over their bills, directions and product suggestions. Another advantage is the low cost of RFID tags and readers since the scanning range is focused in the shopping cart space.

This approach presents an interesting opportunity to make use of the collected data for data mining purposes to have more insight on consumer behavior. Shopping spaces will be able to make adequate changes to fit the customers' expectations.

As future work, the prototyping of such mechatronic system is vital. Thus, error corrections and handling of special cases will be presented with simulations and experimental testing, the goal being a seamless shopping experience.

References

[1] Hui, L., Darabi, H., Banerjee, P., Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. *In*: *IEEE Transactions on Systems, Man and Cybernetics*, p. 1067-080. IEEE Press.

[2] Pesonen, N., Jaakkola, K., Lamy, J., Nummila, K., Marjonen, J. (2009). Smart RFID Tags. *In*: *Development and Implementation of RFID Technology*, p. 171.

[3] How microcontrollers work. *In*: How Stuff Works, *Electronics*. (2011). http://electronics.howstuffworks.com/microcontroller 1.htm.

[4] PIC – Introduction. *In*: Electrofriends Microcontroller Projects, Circuit Diagrams. (2011). http://electrofriends.com/articles/electronics/microcontroller-electronics-articles/pic/pic-introduction.

[5] Integrated circuits (Chips). *In*: Welcome to the Electronics Club. (2011). http://www.kpsec.freeuk.com.

[6] RFID system components and costs- RFID journal. *In*: RFID (Radio Frequency Identification) Technology News & Features, Web. (2011) http://www.rfidjournal.com/article/view/1336.

[7] Randell, C., Muller, H. Low cost indoor positioning system. Unpublished.

[8] Lawson, E. (2004). New microchip PIC10- The world's smallest microchip. *In*: Microcontroller.com, http://www.microcontroller.com/news/Microchip_PIC10F.asp.

[9] PIC vs. AVR smackdown. *In*: Limor. (2011). http://www.ladyada.net/library/picvsavr.html