Smart Shopping Cart for Automated Billing Purpose using Wireless Sensor Networks

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***Abstract*—With the increasing employment of broad area Wireless Sensor Networks (WSN) in the field of consumer applications, it becomes imperative to address the concerns raised by its application, such as reliability, energy consumption and cost-effectiveness. In this paper, we describe the implementation of a reliable, fair and cost efficient Smart Shopping Cart using Wireless Sensor Networks. Such a system is suitable for use in places such as supermarkets, where it can help in reducing man power and in creating a better shopping experience for its customers. Instead of making the customers wait in a long queue for checking-out their shopped items, the system helps in automating the billing process. Along with this ability, the system design also ensures detection of cases of deception invoked by dishonest customers, which makes the smart system fair and attractive to both the buyers and sellers. The system design along with the experimental setup are presented. The results are encouraging and with the use of repeaters at appropriate locations inside the supermarkets, our approach illustrates itself to be conceivable for use outside the laboratory, in real world deployment.**

Keywords-Wireless Sensor Networks; broad area WSN; Smart Shopping Cart; Load cell; Image comparison algorithm

I. INTRODUCTION

Enormous amount of advancements in the field of Wireless Communication has given way to several new technologies and fields altogether. One such upcoming field is Wireless Sensor Networks (WSN), which is maturing at a very fast pace because of its suitability in a wide range of application areas. It consists of a large number of small, low-power, cost-effective, autonomous devices termed as sensor motes. When interfaced with sensors and actuators, which could be simple or complex, they play the combined role of environment-sensing, special-computing and wirelessly communicating devices. These factors accompanied by the effectiveness of technologies for miniaturization of hardware (microcontrollers and radio modems, for example), technologies for sensing equipments, technologies for energy saving and scavenging, and the fact that many applications cannot be wired, makes it suitable for various application domains. Examples of such applications are medicine and health care, disaster relief applications, environment and industrial monitoring, etc. [1]

In this new era of consumerism, broad area WSN finds its use in consumer application areas such as Smart Home, Smart Grid, etc. The challenges here are to not only make the system intelligent by automation, but also to handle the concerns that are raised due to the automation process such as probability of false alarms, energy consumption, cost-effectiveness, etc. Since many sensor nodes are required over a broad area for environment-sensing, the system design needs to concentrate on aspects such as the choice and placement of sensors within the area, communication among the various nodes so that it works reliably with minimum energy requirement and be cost-effective at the same time. In this work, we take the particular case of supermarkets, where our design based on WSN is used to address the following issues:

1) Customer dis-satisfaction because of long waiting time for check-out process, and
2) Involvement of a lot of man-power, which is expensive.

In order to achieve this, we have come up with a design that automates the billing procedure and saves the customers' time. Automation has its own problems. Absence of human operators can potentially lead to inconvenience when the underlying technology fails. It can also lead to dishonest behavior of the customers. We propose and implement a solution that has redundancy built into it in order to reduce the probability of failure, and has three main benefits:

1) It creates a better shopping experience for the customers by saving their time.
2) It minimizes the man-power required at the shopping mall, as the checking-out process at the check-out counters is eliminated altogether.
3) It handles cases of deception if any, thereby making the system attractive not only to the customers, but also to the sellers.

A number of attempts have been made to design a Smart Shopping Cart with various different functionalities. Awati and Awati [2], describe a Smart Trolley design that concentrates on how to get the customers rid of dragging heavy trolleys and to automate billing, but it assumes all the customers to be honest and hence does not tackle cases of deception, if there are any. Further, Yew *et al.* [3] propose a smart shopping for future where the barcodes are completely replaced by Radio Frequency Identification (RFID) tags and scanners. This idea might take a long time to be deployed as it is expensive both in terms of money and energy. A lot of other works describe how products in a store could be tracked by customers instead of spending a lot of time searching for it.

In this paper, the system design considerably minimizes the overhead of wireless communication among the devices involved in the system as almost every processing is done locally at each cart instead of transmitting packets to another node. Hence even when there are a lot of customers present in the shopping mall, there will not be any deterioration in the performance owing to communication gridlock. Every Shopping Cart is equipped with a sensor mote, a load-cell fitted at the base of the trolley, a camera fitted on the top (also acts as barcode scanner) and a system for local processing and display purposes as shown in Figure 1.

Every customer is identified by the ID of the cart s/he picks for shopping. The Base Station at the payment counter consists of a database that stores information of all the products, and a sensor mote to communicate with all the Smart Carts in the mall. When a customer starts shopping, s/he has to scan the barcode of the product with the barcode scanner present at the cart, after which the product has to be put into the basket. The barcode of the product is wirelessly transmitted by the mote to the Base Station using the IEEE 802.15.4 (ZigBee Protocol) [4] over the ZigBee network. ZigBee is chosen

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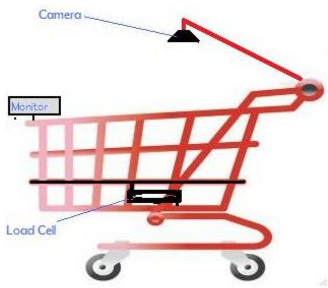

Fig. 1. Smart Shopping Cart

along with the IEEE 802.15.4 compatible sensor motes because they are easily available and mass produced. However, any other short distance radio system will work equally well. In reply, the Base Station sends relevant information about the product, which is used in the decision-making process at the cart. In order to handle all the cases of mistake/dishonesty, the design includes the use of image processing at the cart. After the customer finishes shopping, s/he then proceeds to the payment counter to pay the bill amount and is assisted by an attendant only in the case the system detects discrepancy in the self check-out process of the customer.

The organization of this paper is as follows: Section II presents the detailed system design, Section III gives the implementation details, Section IV discusses the result and feasibility issues, and Section V concludes the paper.

II. Detailed description of the Smart System

The features supported by the Smart Shopping Cart and the idea behind how these features are achieved are explained in the next two sub-sections.

A. Features of the Smart Shopping Cart

The capabilities of the Smart Shopping Cart are listed below:

1) The basic function of calculating and updating customers' bill as and when s/he places the shopped products in the cart.
2) The customer can also track the details of the purchased items as well as the current bill amount on the monitor that is attached to the cart.
3) In addition to the above features, it also includes the handling of the following special cases, which ensures that the system is fair in all respects. All the cases mentioned below are detected by the system.
    a) Attempt to take away products by keeping them into the cart without scanning their barcodes.
    b) When the customer scans a product, but forgets to keep it in the cart.
    c) Attempt to scan one product, but place multiple products in the cart.
    d) Attempt to take away one product of higher price by scanning the barcode of another product of lesser price.
    e) Since consumers are likely to change their mind, our implementation allows for removing any item already placed in the cart, without help from attendant.

Next few sub-sections describe how these functionalities are incorporated into the Smart Shopping System.

B. The Design Idea

The design has been focused to tackle all the scenarios which are mentioned above. As the goal of the Smart Shopping System is automation, the first requirement is to have a barcode scanner attached to every shopping cart. Hence, this design includes a *camera-based barcode scanner*, which is fitted to the cart. The barcode scanner is required to identify a product so that its price can be determined from the database, which stores all the relevant information about all the products. The database in our design is stored in the Base Station, which is located at the payment counter. Some of the information per product that is stored in the database includes its barcode, its name, price and weight.

The *weight* attribute of a product has been chosen for a way to double-check the identity of the product in order to detect deception in the system. A *load-cell* has been configured as a weight sensor. The output of the load-cell is used in the decision making process at the cart. If the weight of a product estimated by the load-cell is not the same as the actual weight of the product, it is interpreted as a case of discrepancy.

The design involves a third level of check to further enhance the decision-making process, which makes use of *Image Processing*. While the barcode of the product is being scanned, a picture of the product is taken by the same camera that also works as the barcode scanner. If a person wants to exchange this product with a costlier one, it will be after scanning the barcode that he will do so. There is a slab attached to the top of the cart which is meant to play the role of placing the products into the cart when it is triggered to do so, instead of the customer having to put the product into the cart by himself. The person places the product on this slab once the scanning is over. Another picture of the product is taken just before the slab lets the product into the cart. Both the images are stored locally in the system present at the cart. An *image comparison algorithm* is run on these two images to find if they are the same products. If they are not found to be the same, it is interpreted as a case of discrepancy. The two images are removed from the memory of the system just after obtaining the result from the algorithm in order to restrict the memory usage of the systems at the cart.

The processing is done locally instead of transmitting the image for every product to the Base Station for comparison, in order to reduce the overhead on the wireless communication, which makes it energy-efficient. This also ensures that the system gives the same performance even with a lot of customers in the store shopping at the same time.

C. Operation of the Smart Shopping System

A customer enters the Smart Shopping Centre. On entering, s/he first picks a Smart Shopping Trolley. Each trolley is given a unique ID and every customer is associated with the ID of the trolley chosen. A typical trolley is expected to look like the one shown in Figure 1. The functioning of the system is listed below:

- When the customer picks up a product that s/he wishes to purchase, s/he first scans the barcode of the product using the barcode scanner and then places it on the slab of the cart, which is meant to play the role of putting the products into the cart when it is triggered to do so. While the customer is scanning the barcode of the product, a picture of the product is taken and stored in the system's memory. The barcode and the cart ID are transmitted as two different fields in a single Zigbee packet by the sensor mote on the cart to the Base Station. An additional field called the *attendant-flag* field is sent only in case of discrepancy.
- At the Base Station, this transmitted information is received by the sensor mote attached to it. This information is then used to fetch relevant information about the product from the database corresponding to the barcode. The database consists of the following details at least: the barcode, name of the product, price and weight. The weight and price fields corresponding to the received barcode are extracted and kept aside.
- Meanwhile, at the cart, the slab still holds the product and another picture of the product is taken *just before* the slab lets the product into the trolley. An image comparison algorithm is run once it has both the images. Depending on whether the

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images match or not, it sets the *attendant-flag* field, which is later transmitted to the Base Station for it to take appropriate actions.

- Once the product is inside the trolley, the role of the load-cell comes into play. The weight of the product is estimated and then transmitted to the Base Station using the same mote on the Smart Cart.
- At the Base Station, the weight which is received from this cart is compared with the weight that was retrieved earlier from the database corresponding to the same cart ID. Depending on whether the weight matches or not, appropriate actions are taken.
- This procedure is repeated for every product the customer purchases. Finally, when the customer finishes shopping, s/he goes to the counter in order to pay the bill amount. In case of any detected discrepancy, an attendant verifies the self-checkout process carried out by the customer. The attendant is signaled by the User Interface present in the Base Station.
- If the two weights are found to be equal *and* if the Base Station does not receive the attendant-flag field, then on entering the customer's cart ID on a particular field in the user interface, it displays the detailed bill of the customer's purchase along with a green symbol. This implies that the customer can pay the bill amount and carry on.
  On the other hand, if the attendant-flag field is detected *or* if the two weights are found to be different at the Base Station, then on entering the customer's cart ID, it displays a red symbol and an alarm sets off, indicating that an attendant has to request the customer to wait for the check-out process again.

If a customer changes his mind, the reverse process has to be carried out. After the customer takes the product out, it has to be scanned and the image of the scanned product is then captured. The Base Station has been programmed to handle this case which enables the customer to do so. This implementation also takes care of all discrepencies in the same manner as described above.

III. Implementation Details

A prototype has been made based on the the same design idea. The various components that are used in the implementation along with the important considerations are explained in details.

1) Barcode Scanner: The prototype uses a camera-based barcode scanner for implementation, which uses a small video camera to capture an image of the barcode and then use sophisticated Image Processing techniques to decode the barcode. We have used a webcam for this purpose, which is supposed to be fixed at the top, facing the slab attached to the cart. The ZBar barcode reader [5] is used for the implementation, which supports many popular symbologies (types of barcodes). It is made to run on the Linux (Ubuntu) Operating System. It also has a user interface that is displayed on the monitor in which the customer can see the green lines along the barcode if it has been detected correctly or a red light if it has not been detected. Figure 2 shows the two conditions.

Fig. 2. User interface of the barcode scanner showing the detection and non-detection of barcode

2) Weight Sensor: A load-cell is configured as a weight sensor. A load cell is a transducer, which is used to convert a force into electrical signal, an analog output voltage. The load cell CZL601-3kg [6] shown in Figure 3 has been used for the experiment, where *3kg* denotes the Rated Capacity of the load cell. The load cell can be chosen based on what precision in weight is required, which in turn depends on what kinds of products are available in the Shopping Store. The cost of the load-cell depends on its precision; higher the precision, higher the price.

One end of the load cell has to be fixed and force has to be applied on the other end so that the deformation in the strain gauge of the load cell is indirectly converted to an output voltage. The load cell is supplied with a DC voltage of 9 Volts with the help of a Transistor-battery.

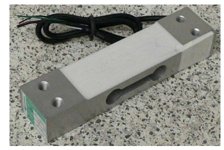

Fig. 3. Load cell CZL601-3kg

TABLE I
Specifications of interest for CZL601-3kg

Rated capacity	3 kg
Rated output	1.948 mV/V
Excitation voltage provided	9 Volts

Rated capacity is the maximum axial load that the load cell is designed to measure within its specifications. The maximum output voltage that can be provided by this load cell is 1.948 mV $\times$ 9V = 17.532 mV. The load cell gives an output voltage which is *almost* proportional to the weight that is applied. It is not exactly linearly proportional to the weight due to many factors such as hysteresis error, repeatability and temperature effects. Readings have been taken as shown in Figure 4, in order to calibrate the output voltage of the load cell for a given input weight. The straight black line shows the ideal response, whereas the blue line shows the actual response. The response flattens out towards the rated capacity.

The output voltage of the load cell is typically in the order of a few millivolts and requires amplification before it can be used. A μA741CN operational amplifier has been used as a negative feedback non-inverting amplifier. An amplification factor of 11 is achieved by the arrangement shown in the Figure 5.

This amplified output is then given to an ADC on the sensorboard. The output of the ADC varies with the amplified output of the load cell, which in turn varies with its input weight. Each cart stores a

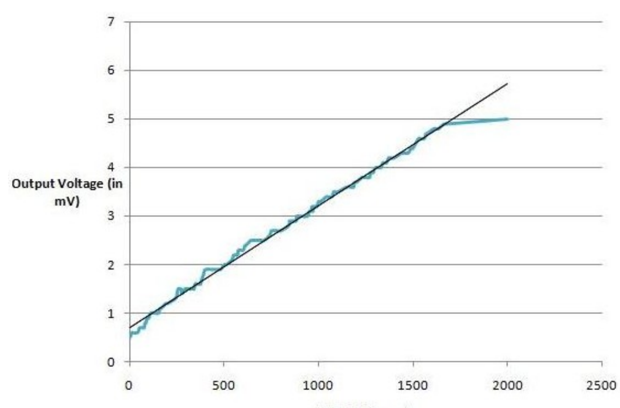

Fig. 4. Plot for Weight versus Output Voltage

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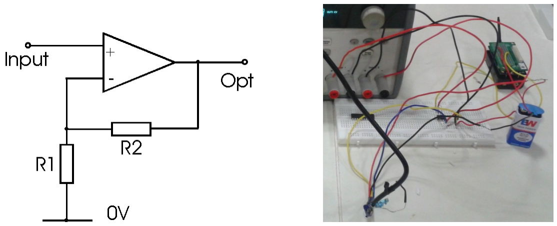

Fig. 5. Voltage amplifier circuit

look-up table, which consists of a mapping between the ADC output values and its corresponding input weight. This is required to compare the weight of the product that has been actually put into the basket with the weight field that the Base Station retrieves from the database. Also, it is advantageous if every cart has its own mapping for the different weight values because load-cells with different precisions could be used for different carts. This effectively means that for different sections of the shopping mall, carts with different precision of the load-cells could be used, instead of using a high precision load-cell throughout, which makes it more cost-efficient.

3) Image Comparison algorithm: The Image comparison algorithm that is chosen for the design is the SIFT (Scale-Invariant Feature Transform) algorithm. It extracts interesting points on the object in the image to provide a *feature description* of the object. These features extracted from the training image are then used to identify the object when attempting to locate this object in a test image containing many other objects as well. This algorithm is apt for the design as the algorithm works even when the object in the two images are not same in size, orientation and scale. So, if the customer places the product on the slab even in a rotated direction, it still identifies whether the product is the same or no. The algorithm works well for all lighting conditions except for very extreme lighting condition, i.e., with almost no light in the ambience.

4) Sensor mote at the Smart Cart: All the Smart Carts are equipped with a Crossbow IRIS-XM210 [7] mote running TinyOS [8] Operating System, along with a MDA100CB sensor board [13]. The mote is connected to the system which is present at the cart via USB cable for monitoring and display purposes. The system at the cart is programed to calculate the weight (with the help of the look-up table) two seconds after the product is being sensed by the load cell so that even if the product is dropped with a great force into the cart, it does not estimate a wrong weight based on the initial momentary thrust on the load-cell. The same sensor mote is used to transmit all the information to the Base Station - the barcode, the trolley ID and the flag fields.

5) The Base Station: The Base Station resides at the counter meant for payment for bills. A PC with an IRIS sensor mote is used to communicate with the Shopping Carts. The database which contains the information of all the products that are present in the store, resides in the PC. MySql database has been used for the implementation. It consists of a table which consists of the following fields: (i) Barcode ID (Primary key), (ii) Name of the product, (iii) Price, and (iv) Weight of the product. The PC also supports a GUI meant to assist the customers to pay their bill amounts and to alert the attendant in cases of discrepancy. Figure 6 and Figure 7 show the laboratory set-up of the proposed system. Experiments have been conducted using the set-up and various products have been selected for testing purpose. Figure 8 and Figure 9 show the UI at the Base Station, in which the red and the green light is indicative of whether the system has detected a case of discrepancy or not respectively.

IV. Result and Feasibility

The experimental set-up is tested for various test cases, with various products tested for all the possible cases mentioned in

Fig. 6. Prototype model of a Smart Shopping Cart

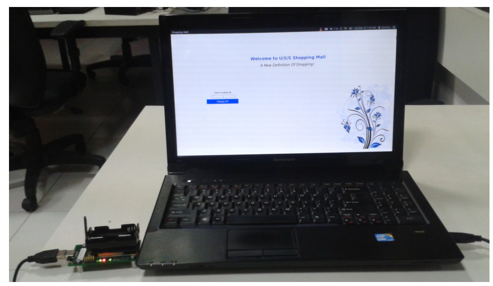

Fig. 7. Prototype model of Base Station

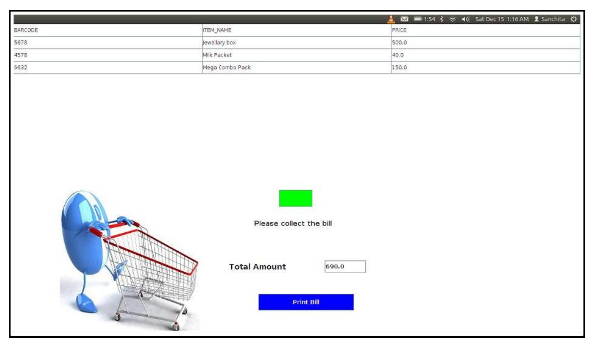

Fig. 8. Generated bill with the Green indicator

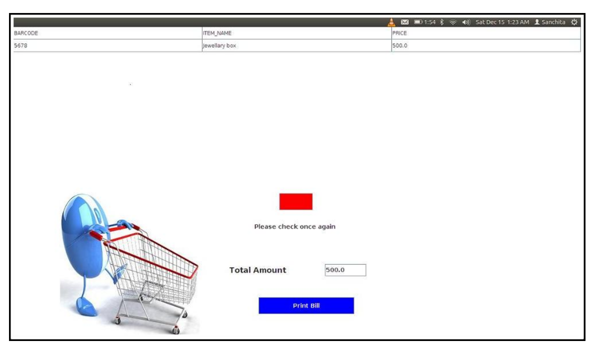

Fig. 9. Generated bill with the Red indicator

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Section II. When the system is tested with a single Shopping Cart and a Base Station, it gives the correct result for all the cases except for the case when the lighting condition is very poor, i.e., when the lighting condition in the environment is very dim/dark. This is because the object in the image cannot be recognized because of the darkness, due to which the SIFT algorithm fails to extract the key points of the object. The lighting in a store is expected to be bright. Low lighting conditions can be indicated on the smart cart by setting the attendant flag. This attendant flag is the same as the one set when weight or images do not match.

Next, we observe how much time it takes for the entire process to take place with respect to the distance of a Shopping Cart from a Base Station. This is required in order to decide on the placement and the number of repeaters inside the Shopping Mall. The processing time includes the time taken by the cart to generate a decision and the time for the wireless communication between the Base Station and the Shopping Cart. Figure 10 shows a plot of the processing time against the distance of the cart from the Base Station. This variation in the response time is mainly due to the time taken for the wireless communication, as the time taken in decision-making at the cart is approximately the same every time.

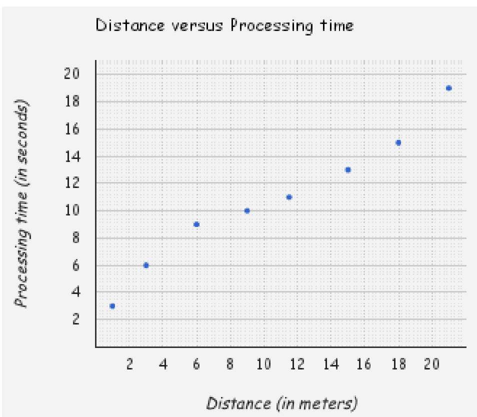

Fig. 10. Distance versus Processing time

The range for mote-to-mote communication is found to be 21 meters inside a busy building at our Campus. This brings in the need for wireless repeaters depending on the dimensions of the Shopping Mall. According to the information gathered, the typical area of a Shopping Mall is about 2,500 square meters per floor [14]. If we consider the layout of such a store to be a square (for a rough estimation), the length per side turns out to be approximately 50 meters. This implies that if the system has to be deployed in such a place, there has to be few repeaters located at different positions in order to ensure coverage of the entire broad area. The IRIS motes can act as repeaters too if they are programed to do so. If there are 2 payment counters (Base Stations) per floor on the opposite corners, 2 to 3 repeaters per floor will suffice.

V. Conclusion and Future Work

The project successfully demonstrated the possibility of using WSN for developing a Smart Shopping System which automates the entire billing procedure. The system which is developed is highly reliable, fair and cost-effective. It is reliable and fair because of the effectiveness of WSN combined with a highly reliable Image Processing technique. The system is also energy constraint as it uses a passive sensor and it reduces the communication requirement. The decision making process is done locally within the cart, thereby eliminating an overhead to the communication between the motes. Also, the application does not make use of complex routing mechanisms or unicast transmissions; our implementation makes use of the simple broadcast technique to communicate with the Base Station as each cart is associated with a unique ID. The system is cost-effective as it requires only one passive sensor (the load-cell) and a camera-based barcode scanner (which is way cheaper than any other type of barcode scanners) per cart. In the bigger picture, it reduces the man-power requirements.

The effect of multiple users operating at the same time, as well as any spectrum coexistence issues must be studied since the proposed system uses the over-used 2.4 GHz spectrum. The current implementation also does not talk about the placement of repeaters inside a supermarket layout.

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