Smart Kitchen Cabinet for Aware Home

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Abstract— **This paper presents the design and development of a "Smart Kitchen Cabinet" which identifies the grocery items in the kitchen store. The Kitchen Cabinet is augmented with sensors to measure the weight of an item which is updated to a database whenever grocery items are placed or taken out for cooking. The jars in the kitchen cabinet are tagged with Radio-frequency identification (RFID) tag for identifying and tracking the location. The optimal placement of jars (containing different ingredients) attached with RFID tags and antennas are tested for maximum read performance and the experimental results are presented. The system also generates automated shopping list when an item reaches the defined threshold level, which is based on requirement and consumption pattern of family members.**

Keywords-Ubiquitous Computing; Pervasive Computing; Smart artifact; Smart Kitchen Cabinet; RFID.

I. INTRODUCTION

The kitchen is a very important place of a home and cooking is one of the day to day activities. The usual difficulty in a kitchen during cooking is finding the items to be out of stock.

The growing popularity of automated systems indicates the demand of the household devices to be smart and automated to support us in our daily activities. The kitchen is one ideal place where automation at various levels can be done. Daily kitchen activities include stocking kitchen cabinet in relation to necessary dietary regiment, likes, and needs, tastes etc.

Smart Kitchen Cabinet is an innovative appliance that incorporates interactive services. It is an embedded system which consists of a touch screen Liquid Crystal Display (LCD), load sensors, Radio-frequency identification (RFID) reader and tags to provide complete awareness about ingredients and availability information for better kitchen management. The features of the cabinet are: inventory management of grocery items, automatic shopping list preparation, item identification and tracking and balanced diet cooking.

The contribution of the paper is as follows: 1) a location sensing and tracking algorithm for grocery items used at home using UHF RFID and load sensors. 2) Development of an embedded inventory management for kitchen groceries. 3) Deployment results in actual kitchen environment. 4) Engineering of Smart Kitchen Cabinet. 5) Optimal placement of RFID antenna and Tags.

The remaining of the paper is organized as: Section II discusses about the related work in this area. The system architecture and overview are described in Section III. The entire system testing and field reports are presented in Section IV. The limitations of the smart kitchen cabinet are mentioned in Section V. Conclusion and future work are described in Section VI.

II. RELATED WORK

A prototype [1] called "Smart Kitchen" that enables traditional meal preparation and healthy cooking by raising awareness about facts on nutrition's present in food ingredients. The sensors are used to detect cooking activities and provide feedback to the user about nutrition information

Context-aware cooking [2] is implemented using augmented cutting board and sensor enriched knife. The cutting board is fixed with load and acceleration sensors to identify the type of food used. Microphone is used to recognize the cutting sound and a camera to identify the object.

Instrumented kitchen to automatically capture, share, and exploit semantically annotated cooking experiences has been realized in [4]. All necessary information should be observed from the user's natural course of actions during the preparation process, such that even users without any knowledge about ontologies are able to create and benefit from semantically represented recipes.

Bonanni, et al. [5] presented an augmented reality interface based on a model of the user, the task and the environment that projects information on the status of work surfaces, storage and tools directly on the objects and spaces where users direct their attention. This prototype uses range finder to measure the surface temperature of food in pans on the range. The temperature of the water in the tap is sensed using heatsink and represented by different light colors. 4D FridgeCam is an augmented reality interface that projects the contents of the refrigerator directly onto the door in such a way as to add location and time-based information. Augmented Cabinetry is an active inventory system that reduces the time required to locate items in the kitchen cabinets.

The accurate location sensing of different objects in a smart shelf using Ultra-high frequency (UHF) RFID technology is presented in [7]. Reference tags are kept in the shelf for location identification. The Received Signal

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Strength Indicator (RSSI) value along with the tag interference level is used for locating an object.

Experimental tests for detecting the pharmaceutical items in a small cabinet using UHF RFID operating at 860MHz to 868MHz are demonstrated in [9]. They achieved a maximum of 61% full detection rate by using four antennas in a cabinet.

Our development work describes practical implementation of embedding intelligence into existing kitchen cabinet for load sensing, location tracking and automatic shopping list preparation resulting in inventory management of grocery items in the kitchen. The RFID read performance with different type of grocery items used in kitchen environment is also presented. The system achieves better read performance by using two antennas and the placement of tags as described in Section IV.

III. OVERVIEW AND ARCHITECTURE

A. System Design

This section comprises technical description of the system. RFID tags are used for identifying the item and load sensors are used for measuring the weight of items as well as locating the items in the cabinet. The RFID tags are attached to the containers and the load sensors are kept under the partitions of the cabinet. RFID antennas are mounted inside the cabinet. The placement of RFID antennas and tags [3] is tested for maximum read performance. When a container arrives/departs, the algorithm identifies the occurred event and updates in the database. The entire application is ported into an embedded platform based on Intel Atom processor. The user can interact with the system through a GUI.

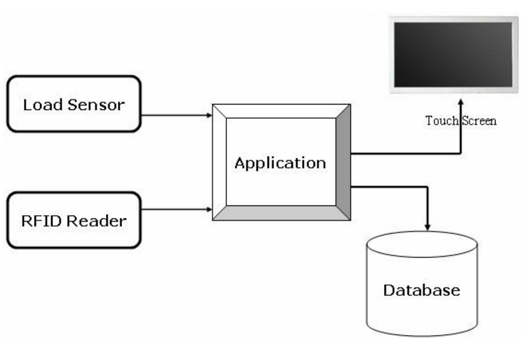

Figure 1. System Overview.

The functional representation of the system is shown in Figure 1. The sensors sense the environment and send the data to the application. The application analyzes the data, decide the action to be taken (IN/OUT) and update in the database. The user can interact with the system through the touch screen monitor. The entire system is deployed in a kitchen of C-DAC, Guest house (Figure 2) for testing purpose. State transition diagram of smart kitchen cabinet is shown in Figure 3. It shows the entire activity of the system. User has to set all necessary fields like family setting, reminder - menu setting and mapping tagID with an item. Once initial settings are done, the system is ready to function. Monitoring weight state is continuously running in the system, if any weight variation occurs, the state is transited to the finding item state which finds and detects the item.

Figure 2. Deployment of Smart Kitchen Cabinet in C-DAC, Guest House.

Detected item and its weight are stored in the database along with partition. When an item is found to be below the specified criteria level, the shopping list state is triggered. This state generates the shopping list and sent to the user through e-mail/SMS/printing according their request.

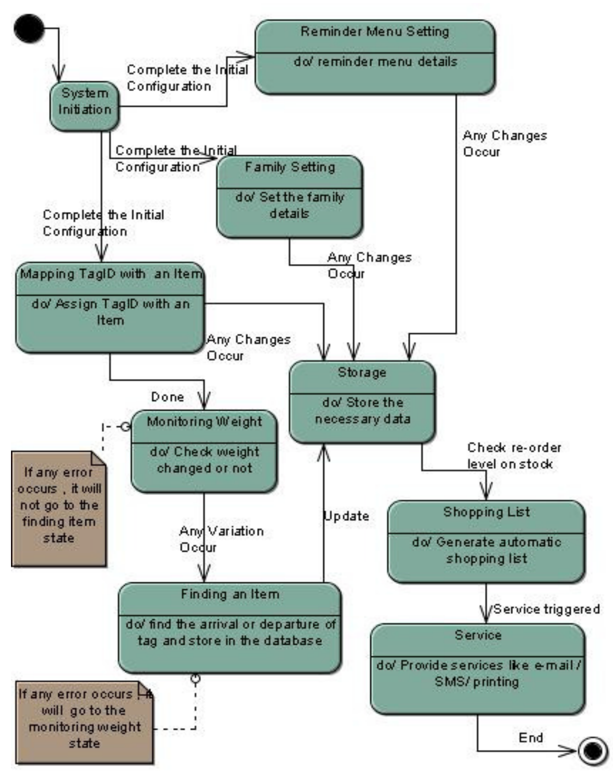

Figure 3. State Transition diagram of Smart Kitchen Cabinet

B. *Identifying and Tracking Algorithm*

The System monitors the weight over the partitions (A and B shown in Figure 2) continuously. The weight measurement is done with a minimum delay between each cycle for the load sensor to get stabilized. An event is said to occur when the difference of the weight of current cycle (ith cycle) and previous cycle (i-1th cycle) exceeds a specified threshold $((W_i - W_{i-1}) > Th)$. The occurred event may be any one of the following 1) Arrival of a new item 2) departure of an existing item 3) False Variation. If the difference value is below the threshold value, then it might be of false variation due to user's hand pressure. It represents no action has to be taken. If the weight output of the current cycle is greater than the previous weight value, then an item has arrived. The current RFID scan (T_n) is compared with the previous RFID scan (T_o) to identify the arrived tag. (Tn ∩ To) gives the common items in current and previous RFID scan. Subtracting (Tn ∩ To) with the current RFID scan (Tn) gives the tag ID of the new arrived item. In case of arrival event, the database is updated with the arrived tag information and weight value. Otherwise, an item has departed from the cabinet. Again, the new and old RFID scan list is compared to find the departed tag. The item is marked as "OUT" in the database. The pseudo-code of the algorithm is described in Figure 4. The available items are listed out with the details like location and quantity to the user.

//W_{i-1} Weight output of i-1th cycle.
//W_i Weight output of ith cycle.
//T_o Represents set of existing tags (Set of tags read in previous scan).
//T_n Represents set of tag read by current scan.
//Th Threshold.

```
IF((Wi - Wi-1 ) > Th) THEN
        IF(Wi > Wi-1 ) THEN
                // A New item has been arrived
                Incoming Item = Tn - (Tn ∩ To )
                Item Weight = Wi - Wi-1
        END IF
         ELSE
                // Depart of an existing item
                Departed Item = To - (Tn ∩ To )
                Item Weight = 0
         END ELSE
END IF
ELSE
                // Error due to hand pressure
                //No action to  be performed
END ELSE
```

Figure 4. Pseudo-code of Identifying and Tracking Algorithm.

C. *Inventory Management Functions for kitchen*

Inventory management includes managing the grocery items, efficient utilization of grocery items and communication to the user [6].

1) Monthly requirement of a family:

The amount of item (Cqty) used per day is found out from the weight variation and logged in the database. From the Cqty, the required consumption (R_{qty}) of an item for a particular time period (T) is calculated using the following formula.

$$\text{Rqty} = \sum_{i=1}^{T} \text{Cqty(i)} \quad (1)$$

2) Automatic Shopping List Preparation

$$Cq = N * Rqty \quad (2)$$

A Minimum weight can be set for every item as a threshold limit called as critical quantity (Cq), calculated using formula (2). It denotes the quantity to be stocked for minimum number of days (N). For an example N=2 means the available quantity should serve the family for at least 2 days. When the quantity of an item goes below critical quantity; it is automatically added in the shopping list along with the quantity (Sqty) need to buy. The Sqty is calculated with the help of formula (3). Ts represents shopping interval and Aqty represents available quantity.

$$Sqty = Rqty * Ts - Aqty \quad (3)$$

Once the shopping list is generated, it should be communicated to the user either by message/mail as per their request. The list is also displayed in the GUI.

D. *User Interface*

The user can interact with the system through Graphical User Interface. The following settings can be made through the GUI. User has to enter the details such as number of adults in the family , number of children in the family, number of guest (adult and children), number of days the guest will stay, alert service such as SMS or E-Mail or both and alert time.

User has to set the details like mapping tag ID with the item, brand name, empty container weight, the quantity to be stocked for minimum number of days and Shopping interval. The reminders can also be set by the user. Recipe preparation tips are provided. The system suggests a suitable recipe that can be prepared from the available groceries.

IV. TESTING OF SMART KITCHEN CABINET

A. *RFID Testing*

1) Materials Used: A cabinet made up of metal and wood with 4 partitions, a wooden Cabinet, UHF RFID reader from SIRIT operating at 860MHz to 868MHz, omni directional RFID antennas from Poynting, UHF passive RFID Tags operating at 860MHz to 869MHz, load sensors from loadstar, plastic containers of different height and size, porcelain containers, glass containers, Tupperware

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containers, stainless steel containers and grocery items are used. The cost of the materials is listed in Table I.

TABLE I. MATERIAL COST

Material	Quantity	Cost (INR)
RFID Reader	1	109031
RFID Antenna	2	11975.97
RFID Tag	20 Approx	998.00
Load Sensor	16	318560.8
Atom Processor Kit	1	70,000
Cabinet	1	25,000

2) Test 1:

The test had been carried out in the Cabinet (100 x 39 x 70 cm) made up of both metal and wood (shown in Figure 6). The test was conducted in our UBICOM laboratory.

Scenario 1:

Initially, the test was carried out with empty containers with tag attached on the side of the containers. Later the containers were loaded with grocery items. The tag detection rate of the containers was tested for different antenna position. Initially a circularly polarized antenna was mounted on the top of rack1 facing downwards. The racks were divided into grids and tested the detection rate in each grid. The read performance was around 77.7% in rack1, 20% in rack 2, 33% in rack 3 and 25% in rack4 shown in Figure 5.

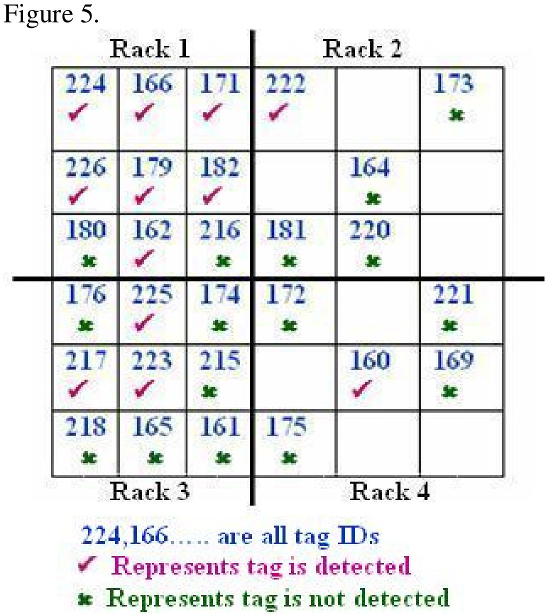

Figure 5. RFID detection result for single antenna

Figure 6. Cabinet made up of metal and wood.

a) Scenario 2:

There were several undetected tags in scenario 1 due to tag collision and tag orientation. In order to increase the detection rate, two antennas were used. One antenna was placed on the right side of the rack 2 and another on the left side of rack 3. The detection rate was 85.7% in rack 1, 100% in rack 2, 85.7% in rack 3 and 62.5% in rack 4 shown in Figure 7.

In glass and porcelain containers, the tag was read by the reader when it is fixed with some air gap as shown in Figure 8 a) and b). In stainless steel containers, the tag was not read by the reader at any position. The RFID detection rate in different containers, materials and the effect of placement of antenna and tags are listed in table. II.

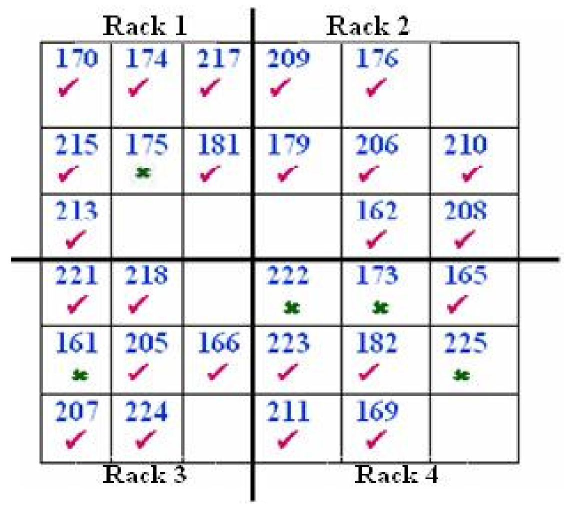

Figure 7. RFID detection result for two antennas

TABLE II. RFID READ PERFORMANCE

Container Material	Content loaded in Container	Tag Placement in Container	Antenna Placement in Cabinet	Read Performance
Stainless Steel	Anything	Anywhere	Anywhere	Very poor
Plastic	sugar, salt	Fix tag with air gap (may be in the cap, or with some space in side)	In the rack where the antenna is kept	Good
Plastic	oil	Side	In the rack where the antenna is not there	Poor
Plastic	oil	Side	In the rack where the antenna is kept	Good
Plastic	Items like dhal, rice, flour etc	Side	Any rack	Good
Small Size Plastic Containers	Anything	Side	In the rack where the antenna is	Poor

			not there	
Small Size Plastic Containers	Anything	Side	In the rack where the antenna is kept	Good
Glass	Anything	Side with air gap	Anywhere	Good
Porcelain	Anything	Side	Anywhere	Good

(a) (b)

Figure 8. Tag attached with air gap in (a) Glass container and (b) Porcelain container.

b) Scenario 3:

We have found experimentally, that by adhering to the following conditions given below, the detection rate is improved to 100% (as shown in Figure 9).

- Small containers should be kept closer to the antenna.
- The sugar, salt and oil containers should be kept in the racks where the antennas are placed.
- Ensure that the containers are kept in such a way that it should not touch each other and also the corners of the rack.
- The grocery item inside the container should be below the level of the tag.

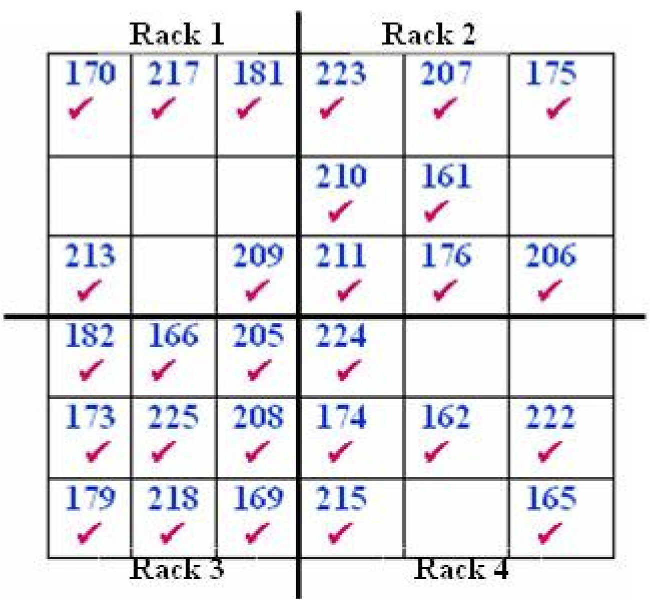

Figure 9. RFID Detection Result for scenario 3.

The RFID connection between the reader and the tags were found to be not stable in the containers having sugar, salt and oil.

3) Test 2:

The system is deployed in C-DAC guest house shown in Figure 2. The cabinet (100 x 37 x 62 cm) is made up of wood and has two partitions. The problems faced during the field testing and the solutions followed are listed below:

- Generation of shopping list:

When a container was taken out of the cabinet, the tagged grocery item was added to the shopping list. This was a logical error in the shopping list preparation module. The error was corrected by measuring the weight of the tagged grocery item after the container is placed again.

- RFID tags Arrive and Depart event problem:

Our application was based on events generated by the RFID reader. The containers with salt, sugar, and oil items, generate arrive and depart events frequently; even though the containers were kept stable in the RF field.

The tag ID and weight variation information was maintained in separate queues. When a container was kept inside the cabinet, the arrive event occurred. The arrived tag ID and the change in weight were added in the RFID queue and load sensor queue respectively. As per the queue concept, the first element of both the queues were taken out and updated in the database. Because of occurrence of false arrive and depart events, the queue concept could not be successfully used for our application.

Solutions:

The following modifications were made in our application: If both queues had an item, then the database would be updated otherwise it might be because of false arrive/depart event. Therefore, the elements were removed from both queues. Even after the modification, the problem was not solved completely.

We used the polling method for RFID tag identification. When there was a change in weight, a new RFID scan was initiated and compared with the previous scan to detect the occurrence of an event.

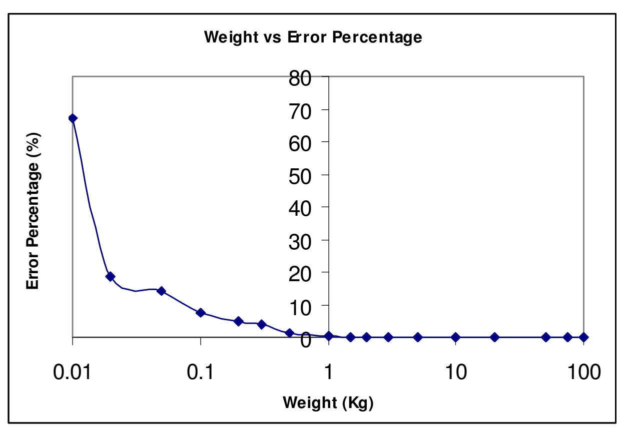

Figure 10. Weight versus Error Rate measurement.

- The user's hand pressure was also measured by the load sensor, while keeping the container inside the cabinet. Hence a delay was introduced in weight measurement for the load sensor to get stabilized.
- RFID connection was not stable in sugar, rice, and salt containers due to water content.
- Load sensor accuracy problem:

Solutions

Tested load sensors with standard weights. Error rate was very high for small weights and decreasing to zero approximately for the weights above 1 Kg as shown in Figure 10. It was observed that the error rate was better for the maximum load capacity of the load sensor.

V. LIMITATIONS

When an item in the container is changed, the user needs to update it. RFID connection is not stable in sugar, oil and salt containers. The placement of tags on these items can be determined experimentally for better read performance. More accurate load sensors can be used to improve the accuracy of the measurement system.

VI. CONCLUSION AND FUTURE WORK

Development of Smart Kitchen Cabinet is an effort towards kitchen automation using ubiquitous computing technologies. The system identifies the grocery items in the kitchen store. The Kitchen Cabinet is embedded with sensors to measure the weight of an item which is updated to a database whenever grocery items are placed or taken out for cooking. Based on the database information the various services offered by Kitchen Cabinet such as inventory management and automatic shopping list preparation are useful and helping us to manage the kitchen activities effectively. The optimal placement of RFID antennas and tags are analyzed for the particular cabinet and the results are presented.

The smartness of the cabinet can be further extended by adding more functionality like Nutrition-aware cooking and personalized cooking. Image processing techniques could also be explored to identify the grocery item inside the container.

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