SmartWave –Intelligent Meal Preparation System to Help Older People Live Independently

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Abstract. As we age, simple everyday tasks become difficult to perform. Simply enjoying a hot nutritious meal may be difficult because of the natural impairments and declines in health conditions. The numerous steps required in preparing a meal and operating a microwave oven can become overwhelming due to visual, hearing, cognitive and/or neuro-motor declines. In this paper we discuss the SmartWave system, a pervasive microwave based cooking system which makes it easier for elderly people to enjoy a hot meal without having to read cooking instructions or interact with the microwave buttons. Additionally, SmartWave provides memory and coordination assistance to aid elderly with minor cognitive impairment. We describe the design and implementation of SmartWave, and discuss its integration with a smart home environment. We also describe a sample usage scenario and present the results of a study that we conducted to explore the elders' views on the usability of SmartWave.

1 Introduction

As we age, we experience normal decline in vision, hearing, cognition and movement. The cost of home health services for older persons with disabilities is increasing with the rapidly elder population. Today, one in ten elders in US suffers from Alzheimer's disease (AD) and it is estimated that 1 in 5 elders will have AD by 2050. These numbers will only increase in the future as the first of the 75.8M baby boomers begin to reach their 60s and 70s in 2008 and 2018 [1]. In 2002, AD resulted in health related expenditures of more than $61B [2] and our health and caregiver system will be increasingly stressed as those numbers increase. Hence, there is a significant need to develop innovative and cost-effective ways to help elders maintain their independence while at the same time reducing caregiver burden.

ADLs or activities of daily living are basic tasks for everyday life. They include eating, dressing and bathing [3]. In order for a person to remain independent, he/she must be able to perform these activities without assistance. For some elderly, even the simplest of tasks such as cooking a microwaveable meal can become overwhelming due to the complex cooking instructions written in small print on the cooking package and the need for memory and coordination in interacting with the microwave oven. In this paper we present SmartWave, an intelligent microwave oven integrated with a smart home environment. The system uses a commercially available microwave along with an RFID reader to allow the microwave to be automatically programmed with the correct cooking instructions. The user simply removes the food package from the freezer, places it on the counter next to the microwave, and the system then walks the user through the cooking process with visual and auditory cues from information contained within the RFID tag on the food package. The system then starts the cooking process once the food has been placed inside the microwave over and the door closed. The system could just as easily been based on the standard UPC barcodes which are currently available on food packets. However, we decided to use RFID to extend the range of usability of the system to include frail elders and elders with minor cognitive impairments, as the process of scanning a barcode is far more complex then just placing an item on the counter.

In the rest of this section, we discuss related work on intelligent kitchen systems. In section 2 we discuss the design of the SmartWave system. Technical aspects of the actual implementation are discussed in section 3. In section 4 we summarize the results of a usability study that we conduced with the help of a local focus group of older people. Finally, in section 5 we discuss our conclusion and future work.

1.1 Related Work

Future kitchen concepts have recently been explored by several industries including consumer electronics, home appliances, durable goods, and the construction industries. Some of the initiatives taken in this direction include Counter Intelligence [4], Restaurant USA [5], IBM Kitchen [6] and Siemens Smart Home [7].

Counter Intelligence introduced kitchen technologies that enable smart utensils and appliances to sense, infer, and react to the environment. Kitchen in essence, is proactively assisting the person with respect to cooking. IBM's Kitchen introduced the concept of central coordination of various appliances like microwave/stove, when one needs various appliances to prepare a recipe. SIEMENS introduced kitchen appliances that work together and gather important information from the internet (for instance, the cooking recipe).

Some of the commercially available smart kitchen appliances include: smart refrigerators [8], smart microwave ovens [9, 10, 11], and finally smart stoves [12]. To this end, TMIO [9] developed a special microwave that can immediately refrigerate your chicken once it is cooked. Another microwave from LG can be connected to PC to download recipes from Internet.

We have looked at the characteristics of Dementia/Alzheimer diseases [13,14,15,16], and looked at studies in health research laboratory [17] and among other papers [18,19,20,21] to learn the essential constraints that need to go into engineering systems for elders with these impairments. The progress report on Alzheimer disease [18] describes ongoing research in the cause, diagnosis, and treatment of AD and also ways to help caregivers support people with AD. At Intel Research Laboratory [19] a study enumerated the key themes regarding the needs and barriers to successful aging and addressed a set of design principles which apply across the stages of cognitive declines. Mihailidis [20] hypothesized that independence might be restored by using a computerized device that prompts and monitors a person as he or she completes an activity. Stanford [21] pointed out that pervasive sensors should assist residents in maintaining their independence, offering assistance only when necessary.

2 SmartWave Design

Consider the example of Maltida, the fictitious 85 year old elder woman who our Smart House is designed for. She has been living alone since her husband's death a few years ago and was recently diagnosed with Alzheimer's disease. This is in addition to common old age ailments such as impaired vision, motor skill degradation, and other cognitive impairments. Her diminished vision makes it difficult for her to read the small preparation instructions printed on food packages, her motor skill problems makes it difficult to operate the microwave oven's controls, and her cognitive ability prevents her from using more complicated kitchen appliances such as the stove. As with most elders, Maltida cherishes the independence she has in her own home, and has thus far been avoiding assisted living care. In order to maintain her independence, she must be able to perform basic ADLs including meal preparation. To support Matilda in her pursuit for independent living, we have designed an intelligent cooking system capable of helping Matilda prepare her own meals independently.

SmartWave is part of a smart kitchen which is contained within our experimental Smart House. We will describe our smart home briefly to show the interaction between the Smart House and the SmartWave. Envisioned by Mark Weiser [22] in the early 1990s, ubiquitous computing is where computation facilities embedded in the environment are available everywhere to assist users in the accomplishing their daily tasks. The computation and interaction is seamlessly and invisibly integrated into physical artifacts within the environments and is always ready to serve us without distracting us from our daily practices.

The ubiquitous vision puts an emphasis on interaction and cooperation among computational devices. This is because the limited capability of a single device to sense and control environments needs to be complemented and enhanced through cooperation and coordination. Using this vision, we designed a smart home environment which promotes successful aging and independent living. Beyond the typical home automation applications, a Smart House for the elderly must simplify and assist in the completion of every day tasks, therefore creating an assistive environment. The system continually monitors context and interprets events to assist the occupant in daily activities, one of which is meal preparation.

2.1 The Smart House Environment and Services

One of the basic services required to maximize the intelligence of a smart environment is an indoor tracking system. This system allows the smart home to make proactive decisions to better serve its occupants by enabling context awareness [23]. Presently we are using an ultrasonic positioning system which uses multiple receivers at fixed locations and transmitters located on the subject allowing location determination via time of arrival calculations.

By placing two transmitting tags on the shoulders of the residents, we are able to determine both their location and the orientation. This location and orientation is important as video cues used in conjunction with the SmartWave system will be displayed on many different monitors throughout the house depending on the residents' room location and the direction they are facing.

The floor plan of our experimental smart house is shown in Figure 1. The ultrasonic location sensors are shown in this diagram. An overhead shot of the actual smart house is shown in Figure 2.

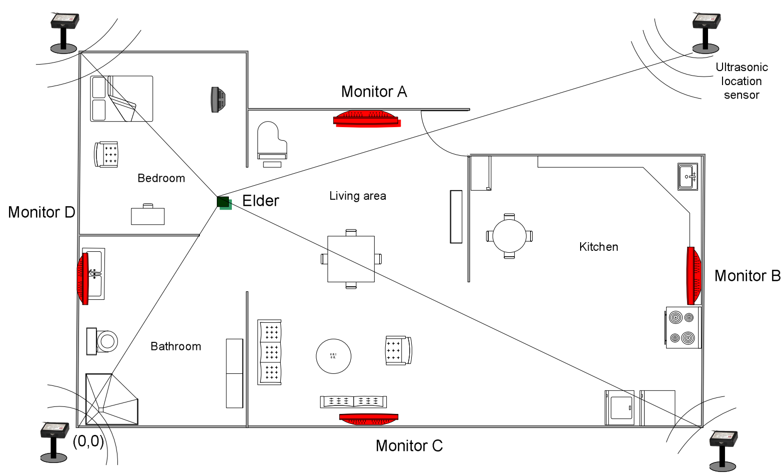


Figure 1 - Floor plan of the experimental smart house

Figure 2 - Picture of the experimental smart house

SmartWave is integrated into the smart house through the Open Service Gateway Initiative (OSGi) framework [24, 25]. OSGi is an open architecture designed for the delivery of services to residential networks. Running on a residential gateway, OSGi facilitates the interaction of services from various sources in an organized and coordinated fashion. This perfectly satisfies our need for a robust framework that can support dynamic context-aware service composition using core services such as our location service. In order to provide an execution environment for services from diverse devices in a residential area, platform independence is a requirement, which is achieved by using Java.

In the OSGi framework [26], a bundle is a deliverable application packaged as a JAR (Java Archive) file. It contains zero or more services specified as a Java interface. Services are registered with Service Registry so that they can be discovered and used by other Bundles. The OSGi framework provides this execution environment for individual services and their interaction among them. We have packaged our location system into an OSGi bundle to provide the service to other services within the OSGi framework. To support rapid application development and facilitate service composition, our middleware provides a set of generic services such as:

- Indoor location and orientation service as described above.
- Voice recognition service. Provides a voice to text translation service

- Multimedia streamer service to deliver video and audio contents (e.g., cues and instructions) to monitor screens and speakers located in different rooms of the smart house.
- Database service enabling storage of various information in relational databases.

2.2 SmartWave Services

The SmartWave and the Smart Kitchen subsystem are integrated to the smart house as a set of bundles offering the following services

- *Monitoring* – by monitoring daily activities over a period of time the smart kitchen keeps track of hydration and eating events, and sends reminders and suggestions to drink or to eat a specific meal. Reminders require a great deal of coordination and the use of several prompting devices. Our reminder system is location and orientation based and makes use of both video and audio cues.
- *Prompting* – Alzheimer's disease makes it very difficult to remember the simplest sequence of steps or procedures. Even cooking a frozen food package can be a struggle. The elder might forget how to open the food package, set the microwave timer and power level, open microwave door, stir the food, or forget to remove cooked food from the microwave. Prompting is a key service offered by the smart kitchen that enhances the effectiveness of the SmartWave system.
- *Notification* – SmartWave makes no assumption about the whereabouts or the activities of the elder person while the food is being cooked. The elder could be anywhere in the house (perhaps watching television). The SmartWave uses the notification service to locate the elder and to send notification that the food is ready, or an additional step is required in the food preparation process.
- *Reassuring* – caregivers may receive special notifications to be reassured that the subject is eating her/his meals regularly.

3. Implementation

3.1 Hardware

The hardware for our SmartWave system consists of many off the shelf parts, including a standard GE microwave which was then modified to allow computer control. The microwave was examined and it was determined that the best way to control the microwave was to embed a microcontroller which would simulate the key presses of the microwave's front panel. This method of interface was chosen so that the microwave would retain all the included safety features. This microcontroller would also need the ability to determine the status of the door, so that the microwave could be programmed and cooking started once the door had been closed.

The PIC-16F628 [27] was chosen as the microprocessor used for the microwave control. The PIC-16F628 was connected to three MAX395 serially controlled switch chips. Each MAX395 [28] has 8 SPST switches on board allowing up to 8 buttons to be simulated. The three devices daisy chained together yielded 24 separate SPST switches which are used to simulate the button pushes of the front panel. Of the 24 SPST switches available, 17 have been used to control the 17 front panel buttons on the microwave model we have selected. The PIC-16F628 was also connected to an additional door switch in an otherwise unpopulated location to provide feedback on the current door status. This enables the host application to query the current door status and only send the start commands once the door has been closed by the subject.

The keypad interface in the microwave is a common row/column configuration, where each button on the membrane keypad provided an electrical connection between a row and column. The PIC-16F628 microcontroller and serially controlled switches are used to simulate the membrane keypad by electronically connecting a row and column. The input to the microcontroller was accomplished via a standard RS232 serial port, providing flexibility in the device which actually controls the microwave.

Controlling our microwave oven is the TINI processor from Dallas Semiconductor [29]. The TINI processor was chosen due to its network connectivity and how it could be easily used to interact with the existing technology in our smart home. Using this processor, we were able to seamlessly integrate the microwave and benefit from the existing technology which is present in our OSGi driven smart house. The TINI connects to the RFID reader and the microwave via two RS232 seria ports. When an RFID tag is detected, it is read, decoded and signals are sent to the smart house via the home network for video/audio cueing and also to the microwave via the serial interface for the cooking information.

A Texas Instruments RFID reader is used to determine which food packet is being scanned and to obtain the cooking instructions from that RFID tag [30], or perhaps stored in a remote database. The database could be used due to the small storage space within the RFID tag itself. In a database implementation, the RFID data would just be an identifier indicating the food packet, yielding a key into the database for the actual cooking instructions and other important information.

The work flow of the SmartWave system is shown in Figure 3. As the elder takes a frozen food packet from the microwave and places it on the countertop, the RFID tag on the back of the packet is read by the RFID reader. The packet descriptor is sent through the TINI to the home computer and then cooking instructions are sent to the PIC microcontroller within the microwave. The PIC microcontroller then electronically pushes the correct buttons on the microwave front panel. ***Figure 4*** shows snapshots of the physical components, including the RFID tags, the SmartWave with the RFID reader, the manufactured PC board installed in the microwave oven and finally the Smart Kitchen area in the Smart House.

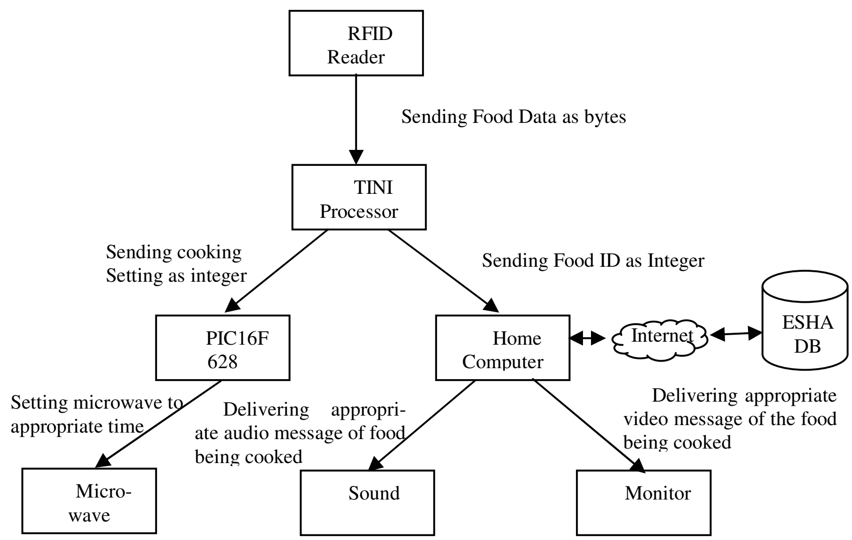
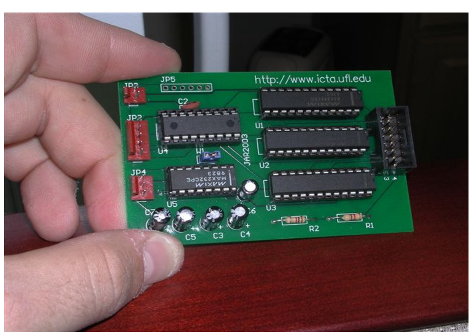
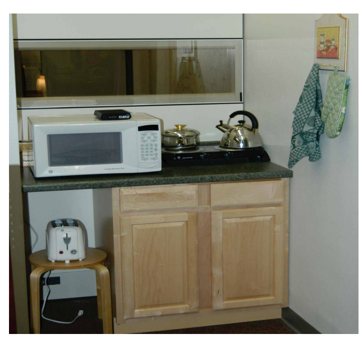


Figure 3 - Workflow and components of the SmartWave system





3.2 Software

The OSGi framework consists of Services which can make use of other services to enhance functionality. The SmartWave service makes use of many other generic services within the OSGi framework. The service interaction flow is shown in Figure 5 below.

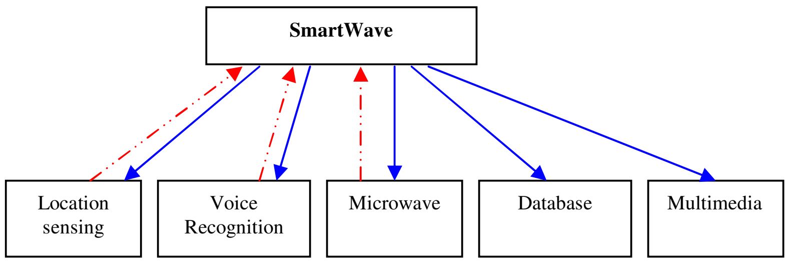


Figure 5 - OSGi service interaction flow diagram for SmartWave

The three dotted pointers to SmartWave describe an event trigger by location sensing, voice recognition and microwave service to SmartWave service. Blue pointer represent service request by SmartWave bundle to other services. There is no event generation from database and multimedia service to the SmartWave.

3.2.1 Database service

The database service, using Oracle 9i, stores various information about food nutrition, complete cooking instruction, person's diseases and health conditions, previously cooked food, personal cooking adjustments, and various sound and video clips related to the meal preparation. The food nutrition data can be downloaded from ESHA nutrition [31] and information about how to cook the food can be stored in the RFID tag. While the RFID tag can contain food description and cooking instruction, food nutritional information is downloaded via the Internet from ESHA. The database service provides access to the nutrition information and is used to potentially guard against violating diet and disease restrictions for the individual user.

3.2.2 Location service

The location service keeps track of the coordinate position and orientation of the user. With information about the house, the location service converts this low level information to higher level information such as "kitchen", "facing microwave", and "leaving kitchen". This information is used as context when displaying visual and audio cues to the user.

3.2.3 Voice recognition service

Based on the elder location, SmartWave activates certain microphones located throughout the smart home and uses certain rule grammars based on possible contexts. This will enable the user to ask for the instructions to repeat or indicate that the food was too hot. This feedback will then be stored in the database and could be used to adjust the cooking the next time this specific meal is prepared.

3.2.4 Multimedia service

The smart home has three flat LCD screens mounted on the walls in the living room, the bedroom and the kitchen. Each LCD display also contains associate speakers. They are connected to the home computer via an analog switch which controls the video and audio output to certain locations. The multimedia service provides play both video and sound directed towards a certain location within the home. To prompt the user or to send a reminder, the SmartWave requests the user location and orientation from the location service and then requests the multimedia service play the video/audio on the requested monitor/speaker.

3.2.5 Microwave Service

Microwave service represents the commercial off the shelf microwave placed in the kitchen. When the microwave bundle is activated, it attempts to establish the physical connection to the microwave. If the microwave responds, the microwave bundle will register the microwave service. Otherwise the microwave bundle will put the registration of the service on hold and continually query for the existence of the microwave. The microwave service, once registered, provides all front panel functionality as easy-to-use methods. Such methods include timeCook(time, power), isDoorOpened(), getMicrowaveState(), etc. If the microwave becomes unreachable, the microwave bundle will automatically unregister the service and wait for it to re-appear.

3.2.6 SmartWave

The following events describe the proactive operation of the SmartWave system.

- Get food id event - When the user puts the food package on the counter, the microwave will obtain the food id and send this information to the microwave service. Microwave service posts this event to the OSGi event framework to be captured by the SmartWave service. The SmartWave service then asks the database service to prepare the pertinent video explaining how to prepare this food. The video typically contains a demonstration on how to open packaging, and other simple steps required to prepare the meal. The SmartWave service requests the multimedia service to play the video on the kitchen monitor.
- Out of date events – If the food is out of date, microwave will send “Out of date event” to the microwave service. Microwave service posts this event to the

framework to be captured by the SmartWave service. The database is asked to prepare the out-of-date video and the multimedia service plays this video on the monitor in the kitchen.

- Un-microwaveable event - If the food descriptor is not of the microwaveable type such as soft drink, ice cream, the microwave will send “un-microwaveable event” to the microwave service. Again, the correct video clip will be displayed indicating that microwaving of this item is not possible.
- Stir event - Some meals require multiple steps before the considered complete. For this, an event may be required during between phases of the cooking. This event is raised when action is required by the user and the appropriate video is displayed.
- Food ready event – After the food is cooked, the microwave sends “food ready event” to the microwave service. This causes the display of the completion video to whatever monitor the user is closest to. This is done by making using of the location service in addition to the multimedia service.

4. Usability Study

The objective of our study was to explore elder views on the current usability of the microwave oven and to test the usability of our SmartWave system. The SmartWave interactive demonstration involved a general overview of the SmartWave, followed by a group demonstration of the SmartWave cooking a frozen entrée, and concluded with all study participants individually preparing their own frozen dinner entrée (Nancy’s Personal Quiche Florentine) with the SmartWave. A background questionnaire was completed prior to the SmartWave demonstration and a follow-up questionnaire assessing the usability of the SmartWave system was completed once the study participant successfully cooked their own entrée.

Disability	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Results**
Low Vision	X	X	-	-	-	X	-	-	3/8 =38% have low vision
Poor Hearing	X	-	X	-	X	-	-	-	3/8=38% have poor hearing
Difficulty with hand tasks	X	X	X	-	X	-	-	-	4/8=50% have difficulty with hand tasks
Memory difficulties/learning disability	X	X	-	-	X	X	-	-	4/8=50% have learning or memory difficulties

Table 1 Summary of health impairments of the study participants

Eight elders (from the RERC-Tech-Aging consumer advisory board) participated in the interactive demonstration of the SmartWave system. Summary of the impairments of the group participants is listed in Table 1 above. The results of the background questionnaire are summarized as follows: Participants ranged in age from 66 to 82 years, with a mean of 75+5.9. fifty percent of these participants were male, and all were white. Sixty-three percent had completed college. Thirty-eight percent lived alone. Seventy-five percent of female study participants prepared three meals on a typical day, with seventy-five percent of male study participants preparing only snacks, or going out to eat, or having their spouse prepare all their meals on a typical day. All study participants had a microwave oven in their home and all reported being 'very satisfied' with their microwave. Eighty-eight percent rated their microwave as being 'very important,' with seventy-five percent using their microwave '6-10 times' during a typical week. Fifty-seven percent reported preparing a frozen food item such as a 'TV-dinner, chicken pot pie, pizza pocket 2-5 times a week.' Eighty-eight percent were 'self-taught' in using their microwave. All study participants reported microwave instructions on frozen food packages were 'not at all difficult to follow,' however forty-three percent reported that if they felt the microwave instructions were too difficult to follow they would resort to 'guessing how much time and power to use when preparing a frozen food item out of a box.' Finally thirty-eight percent reported microwave instructions on frozen food packages as 'somewhat difficult to read.'

The results of the usability of the SmartWave are summarized as follows: All study participants reported the SmartWave as 'not at all difficult to use,' with seventy-one percent rating the SmartWave as 'very easy to use when compared to their present microwave at home.' Seventy-five percent rated the difficulty level of the instructions for the SmartWave as 'just right,' with one study participant stating that the instruction level 'needed to have more steps,' with a second study participant stating 'there were too many simple steps.' Another study participant suggested that the SmartWave be outfitted with a pause button due to the fact that he had dropped his entrée and the video/audio instructions 'got ahead of him.'

One study participant ranked the SmartWave poorly commenting that the SmartWave door was hard to open when compared to her personal microwave however the SmartWave can operate with any door mechanism therefore this was not a factor of the SmartWave but rather the brand of microwave the prototype components were installed onto (she preferred a door in which she could open the microwave by pulling a handle as opposed to having to manually push in a button to open the door).

Sixty-three percent of the study participants reported that they would be 'very willing' to retrofit their home microwave with SmartWave components. The twenty-five percent that were 'not willing' stated that their home microwave works fine for their present needs however would be open to the idea of using a SmartWave in the future if the need arose. Fifty percent of the study participants stated that if they had a SmartWave oven in their home they would use it more often than they presently use their current microwave at home.

When study participants were asked if they had a SmartWave oven in their home would they buy food that was compatible with the SmartWave oven or buy what they normally purchased and seventy-five percent reported that they would buy foods that were specifically labeled 'Compatible with the SmartWave oven.' One study participant stated she would only change her purchasing habits if the food product was 'new and appealing and a second study participant had a concern regarding the possible 'comparative cost' of the SmartWave labeled food products.

This elder sample was found to frequently use and place high value on their microwave ovens at home. Although the elder sample reported both being very satisfied with their present microwave oven at home and less than fifty percent reported having problems reading or following the microwave food package instructions, once the elder group witnessed the SmartWave system they recognized the potential benefit in having this smart technology in their home. The potential benefit the elder group placed in the SmartWave was seen in the high number of elders willing to change their habits and home environment to accommodate the SmartWave oven; this was seen in the high number willing to retrofit their present microwave as well as the high number willing to change which food products they would normally buy to SmartWave labeled food.

5. Conclusion

This paper has presented the design and development of a smart microwave cooking system. The main motivation of our work is to assist the elder population live independently by creating a system that will let them prepare a meal despite age-related impairments and ailing health conditions. Our approach is to make cooking a proactive process undertaken by the smart microwave (SmartWave) by using functionality provided by the smart house. To this end, we have used RFID tags on the food packets to help attain the cooking instructions from the tag itself or from a database. Also, to incorporate great usability, we have provided assistance using video and audio to help with a step by step process of cooking the food. Finally, we have tested our prototype by conducting a study on the usability of the SmartWave system. The results were positive with respect to acceptability, usability and convenience for the end user.

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