Toward Pervasive Computing System to Enhance Safety of Ageing People in Smart Kitchen

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Abstract: Kitchen is the second place where the majority of domestic accidents occur, and in particular oven presents the most principal source of fire accidents in residence. Therefore, enabling kitchen safety is a major factor for ageing people independent living. This paper presents the hardware architecture of our cooking-safe system that targets enhancing safety of ageing people while cooking. The system is based on insightful cooking risk analysis that enables to determine the pertinent parameters to be monitored and measured while cooking. This paper also presents the results of our experimental study that leads us to select the appropriate sensors to constitute the basic building block of our cooking-safe system. The system is composed of sensor nodes to monitor events around oven, then the sensory data is transmitted to a computing unit. The system proactively reacts to hazards in order to prevent cooking associated risks.

1 INTRODUCTION

Cooking is a very important Activity of Daily Living (**ADL**). Statistical studies revealed that cooking enhances survival for ageing people, and can improve their moral feeling as active people (Chen, 2012). Alas, kitchen is the second place where the majority of domestic accidents occur, and in particular oven presents the main source of fire accidents in the residence (Fire Marshal's Public, 2009; Ahrens, 2008). Studies also revealed that unattended cooking is the main leading factor responsible for fire in the kitchen (Ahrens, 2008; Lushaka, 2014). Therefore, enabling kitchen safety is a major factor for ageing independent living.

The need of providing safety for ageing people at home becomes more significant because of the increasing number of ageing people around the world, and particularly in developed countries. In Canada, the proportion of ageing people aged 65 years or over will represent between 23% and 25% of the population by 2036, and between 24% and 28% by 2061 (Martel, 2011; Hall, 2006). In Japan, the population of 65 year-old was about 25.1% of the total population in 2013, and will be 40% in 2050, which is the highest ratio of ageing population in the world (Toshio, 2013). In the United States, the number of senior citizens is also on the rise: in 2010, there were 40.3 million people aged 65 and above, comprising 13% of the overall population. This proportion is 12 times higher than it was in 1900, when this group constituted only 4.1% of the population. By 2050, projections indicate the population over 65 will comprise 20.9% of the population in the United States (Loraine, 2014). In Europe, by 2025 more than 20% of population will be 65 or over, with a particularly rapid increase in the number of over 80s. In the United States, 40% of women and 19% of men aged 65 years and older, live alone and do not have anyone in the home to assist with activities of daily living, provide care when they are sick, or to assist with home maintenance (Jacobsen, 2011). In Canada, 92.1% of ageing people live in private households or dwellings (Canadian Census, 2011).

Cognitive decline in ageing, such as attention and memory problems, have severe impacts on ADL, limiting people to perform cooking. Due to this decline, ageing people are strongly concerned by cooking associated risks (We identify the three major risks during cooking/ in kitchen as fire, burn or intoxication). As consequences, they are often forced to stop cooking or completely move to a nursing home or healthcare facility to prevent dangerous situations (e.g., a fire may occur when an

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ageing person forgets a pot on a burner (Yuan, 2012)). Urgent intervention is required to prevent risks in ADL, which is driven by the following motives:

- The vast majority of ageing people live independently (Gitlin, 2003);
- Most of ageing people wish to remain in their environment as long as possible (Public Health agency of Canada, 2006), even if this stay requires long-term in-home care provision (Wahl, 2003);
- In addition, about 80% of seniors prefer to die at home, not at care facilities (Wahl, 2003).

A possible solution for ageing people to stay at home is to be accompanied by a family member or a caregiver for cooking activity. However, this solution is not practical due to independence and privacy issues. In addition, it has several drawbacks such as high cost and a shortage of qualified professionals. It also requires that ageing person accepts the idea of being not completely autonomous needing help. These factors negatively affect the moral situation of ageing people and consequently complicate the cognitive deficiencies recovery (Sperling, 2011). Therefore, assistive technology is a potential alternative to enhance safety at home.

We present in this paper our attempt to provide ageing people with an assistive technology for safe cooking environment. Our goal is to establish a preventive approach for enhancing safety, with a cooking-safe system that proactively reacts to hazards in order to prevent cooking associated risks. We envision a cooking-safe system composed of sensor nodes that enable monitoring of events around oven. The sensory data is processed according to risk prevention algorithms. These algorithms are based on the results of our experimental cooking risk analysis. In this paper, we introduce the hardware architecture of our cooking-safe system. We mainly discuss the selection of the sensors that has been inferred from our risk analysis and experiential studies. We also present the results of our experimental study including testing sensors in real word environment.

The rest of the paper is organized as follows. Section 2 highlights the terminology used in this paper. Section 3 presents the related existing work. Section 4 introduces our cooking-safe system. Section 5 summarizes the results of our risk analysis and assessment. Section 6 presents the hardware architecture of our cooking-safe system. In addition, it discusses the selected sensors that constitute the basic building block of the system, and sensors positioning in the cooking environment. Section 7 discusses the results of the sensors testing. Finally, Section 8 concludes the paper and presents future work.

2 "RISK" VS. "HAZARD"

There is a need for a clear understanding of the meaning of terms "Risk" and "Hazard" since they are generally used interchangeably in the literature. Risk is defined as "the probability that a negative consequence (e.g. loss) can occur in a given period of time following a specific adverse event" (Marzocchi, 2012). Hazard is defined as "a source of danger" and risk is the "possibility of loss or injury" and the "degree of probability of such loss. Hazard, therefore, simply exists as a source. Risk includes the likelihood of conversion of that source into actual delivery of loss, injury, or some form of damage" (Kaplan, 1981). We distinguish between risk and hazard. We define Risk as the potential of occurrence of an event that yields unwanted results, and we define Hazard as a reason that causes a risk. As an example, let us consider this scenario for an elderly person performing ADL. She/he is cooking a meal, puts a pot on burner and goes to watch TV. After a period of time, a fire occurs in the kitchen. The hazard in this example is unattended cooking, and the risk is fire. Fire occurs and causes unwanted results such as home destruction, losing valuable objects, or death of the person.

3 RELATED WORK

We identified the three major risks during cooking/ in kitchen as fire, burn or intoxication. Our study of the literature reveals that existing research often addresses only one particular risk in cooking (mainly fire), and there is no global solution for kitchen safety. In addition, no research work provides solutions to prevent burn or intoxication.

A basic existing solution to handle fire risk at home is installing fire alarms. The main concern of fire alarms is to detect fire occurrence quickly, so fire rescue agents can intervene in time. However, fire alarms have several drawbacks, particularly for ageing people. These people usually forget replacing alarm batteries regularly. In addition, fire alarms generate false alarms (e.g., in the presence of a small quantity of smock generated by regular cooking). This situation disturbs them, which increases their tendency to uninstall fire alarms at their homes.

Lushaka et al. (Lushaka, 2014) established a more elaborated system that relies on existing smoke alarms to detect a potential fire risk, and consequently, reacts by switching off oven power supply. The system considers only fire risk and depends on existing smoke alarms.

Doman et al. establish a system for assisting ageing people in kitchen through video and audio (Doman, 2011). This system reminds user to follow the correct steps when performing a cooking task, so it can possibly avoid cooking hazards, but it does not react when a dangerous situation occurs. Other intelligent assistive technologies are designed for people with cognitive deficiencies: Li et al. (Li, 2013) propose a design for a smart kitchen environment to assist ageing people suffering from dementia in cooking process. Using the system, caregivers remotely instruct users according to a cooking workflow. In addition, a visual surveillance system with multiple cameras enables to observe cooking conditions, and track user activities and object movement. This system is not completely automatic, since it requires observer intervention and it is based on visual monitoring by cameras, which may be considered intrusive. Sanchez et al. establish a system that assists people in the kitchen and reacts when a potentially dangerous situation is detected (Sanchez, 2013). The system detects rapid variations in temperature and smoke in kitchen, and sends a notification (with camera shots) to the fire department and caregivers. In addition, the system activates exhaust fans and a fire extinguishing suppression system. A number of studies mention oven monitoring as a part of larger systems to track ADL: Alwan et al., (Alwan, 2006) measure oven usage and Wai et al., (Wai, 2011) propose detecting unsafe usage of the oven. Both systems use embedded temperature sensors to measure the burner status, ultrasonic sensors to detect the presence of a pot and electric current sensors to detect the usage of oven and levels of abnormality in the kitchen. Chen et al. (Chen, 2010) propose a system that detects food ingredients based on visible-light cameras during cooking activities to ensure the healthy eating habits. The three discussed systems either require modifications to oven to install sensors, or use visible-light cameras (may be considered intrusive). Yuan et al. (Yuan, 2012) developed an automated top oven monitoring system based on thermal camera to detect dangerous situations. The system alerts user or caregiver when a dangerous situation occurs. The system does not require modifications to oven, so it fits any existing oven and respects user privacy, because it is based on thermal imaging instead of visible-light camera. Since the thermal camera does not process regular images, user privacy is preserved. However, the thermal camera has significant limitations since it is sensitive to cooking heat and smoke.

Few electrical cooking devices equipped with limited safety features are available in the market. For example, Electrolux INSPIRO oven contains programmable cooking modes. According to the selected cooking mode, the oven calculates cooking time and temperature. TMIO society commercializes ovens with tactile screen, and network connection to be remotely controlled. Numerous manufactures integrate LEDs to indicate that an oven surface is hot to prevent burn. However, the concentration of ageing people is on the cooking task itself and she/he may not notice the lightening LED. Generally speaking, safety measures are partially considered in the existing commercial cooking devices. StoveGuard, SafeCook and HomeSensor propose a timer system to switch off an oven if there is no attendance after certain programmed time. Still, risks may occur within this period of time.

To summarize, existing systems propose numerous interesting features to manage risks at home. However, they have several limitations: they focus on aid for only one specific risk situation, they need to be programmed for each type of use and each time they are used, and they provide elevated risks in the case of cognitive deficiencies.

4 COOKING-SAFE SYSTEM

Our proposition to address cooking safety issues for ageing people independent living is to offer pervasive computing support. The system is based on a smart environment infrastructure, especially sensors and actuators distributed in the kitchen area. The system allows sensing cooking activities and offering appropriate interventions.

- Sensors are installed around oven to perform contextual information acquisition. They allow the system to infer the situation during cooking, or detect changes in the surrounding environment (e.g., smoke, burner temperature, utensil temperature, and presence of utensil on burner).
- Actuators are distributed in the residence to ubiquitously alert user of a cooking risk situation. They provide feedback through screens, speakers, or flashing lights, and control appliances in the kitchen (such as switch off oven power).

Sensory data fusion and ambient intelligence techniques enable detection of risk situations with enhanced accuracy and efficiency. Moreover, actuators provide a wide range of possibilities for human-machine interaction including appropriate intervention for each detected risk situation, and an adapted reaction according to user needs.

Building a robust sensor-based cooking-safe environment requires insightful risk analysis. In addition, adequate sensor selection and testing is a significant factor for building a robust system. Therefore, we performed experiments on cooking several kinds of food in normal and risk situations, in order to extract the relevant parameters to monitor and measure to prevent cooking related risks (Section 5). After analyzing risks, we discuss the sensors selected based on risk analysis to build the cooking-safe system (Section 6). Then, we illustrate sensors testing results in order to study the behavior and precision of sensors in real world cooking environment (Section 7).

5 RISK ANALYSIS AND ASSESSMENT

We performed risk analysis and assessment in two phases. First, we reviewed literature to study the characteristics of existing solutions. We also extracted the pertinent parameters of cooking risks. As results of this phase, we identified the most frequent hazards that lead to risk situations as follows:

1. Unattended cooking,
2. Forgetting a pot on a burner;
3. User turning on a burner, but forgetting to cover it with a pot;
4. User turning on a burner, but placing the pot on an incorrect burner,
5. Burners are at dangerous temperatures and oven is left unattended;
6. A pot is removed from oven but user forgets to turn it off.

This phase also enabled us to identify the major risks during cooking activities as: fire, burn, and intoxication.

Second, we built an experimental setup to study these three major identified risks. We present a summary of our experimental results (the complete study with comprehensive results is presented in another paper).

5.1 Experimental Setup

We investigated several hazardous situations during cooking in order to extract pertinent parameters related to cooking risks. We performed series of experiments that reflect the real world cooking scenarios with varieties of cooking materials. The goal is to establish the relation between the parameters and triggering risks. In order to focus only on sources of risks, independently from oven characteristics (e.g., gas factors related to gas oven), we used an electrical oven. Following are a summary of the studied parameters for each risk:

Fire: we observed the parameters: Volatile Organic Compound (VOC), Alcohol, and CO gases concentrations in the cooking smoke gas.

Burn: For burn risk by splash and by contacting hot objects, we observed the following parameters: relative humidity, utensils temperatures, burner temperature, and presence of object over burner.

Intoxication: we observed the concentration of CO gas in the cooking smoke.

5.2 Fire Risk Analysis

We observed cooking several types of food, i.e., fish, meat, onion, peppers, and spaghetti. Also, we experiment heated oil (i.e., 50ml of canola oil) in a frying pan for 8 minutes until oil starts to shudder. As a summary of our results, there is a correlation between fire triggering and the concentrations of certain chemical components in the cooking smoke, so detection of fire would be possible. Our experimentations lead us to determine the pertinent parameters to be monitored in order to detect fire triggering in early stage i.e., VOC (e.g., aldehydes, alcohols, acids), hydrocarbons, and inflammable gases. Our experimentations also revealed that there are boundaries between normal and dangerous situations during cooking, with respect to the concentrations of VOC and Alcohol gases in the cooking smoke, i.e., if Alcohol or VOC concentration in the cooking smoke exceeds 170 ppm, then there is a potential fire risk situation.

5.3 Burn Risk Analysis

We distinguish two types of burn linked to cooking: 1st by direct contact between skin and hot cooking utensil and burner; and 2nd by splash of hot liquid on skin. As a summary of our results:

* For burn by direct contact, detecting the presence of utensil on a burner is required in order to start monitoring its temperature. If there is no utensil on burner, monitoring burner temperature is required. In addition, we found that there are distinct thresholds between normal and dangerous situations.

* For burn by splash, we experimented heating liquid using kettle and saucepan with/without lid for better understanding of the variations of relative humidity (%RH) while liquid is boiling. As a summary of our results: A slight increment in %RH before water simmers, means that there is a release of small quantity of steam, and indicates that there is an object heated on burner. In addition, an increment of 5%RH indicates that water is simmering so the global water temperature is around 100°C. Therefore; rapid variations in relative humidity is an important indicator of water temperature in a cooking utensil, and consequently a potential splash burn risk.

As conclusion, it is feasible to prevent splash burn risk based on measuring relative humidity, because it does not change significantly unless a liquid is being heated. In addition, the experimentations enabled as to identify the pertinent parameters to be monitored and measured around oven in order to prevent burn risk. For burn by contact with hot object, the parameters are: temperature of cooking utensils, temperature of burner, and presence of an object on burner. For burn by splash, the pertinent parameters are: relative humidity and presence of an object on burner.

5.4 Intoxication by Gas/Smoke Risk Analysis

Carbon monoxide (CO) is the most dangerous component in the cooking smoke. It is an odorless, tasteless, colorless poisoning gas that may cause death because of its binding to hemoglobin. It is produced by the incomplete burning of organic materials. The concentration of CO becomes immediately dangerous when it reaches 1200 ppm. Carbon dioxide (CO_2) is another gas in the cooking smoke that is less dangerous for health. It becomes dangerous if the concentration reaches 40,000 ppm.

Our study reveals that CO is released in the cooking smoke. Combustion of nutritional elements is either complete (produces Carbon dioxide CO_2) or incomplete (produces CO).

As conclusion for the intoxication risk, CO concentration is a parameter to be monitored around oven in order to prevent intoxication by gas/smoke. There are boundaries between normal and intoxication risk situations. The normal concentration of CO in the cooking smoke is around 40 ppm. There is a potential intoxication risk, if CO concentration exceeds 900 ppm.

6 HARDWARE ARCHITECTURE AND SENSOR SELECTION

Our cooking-safe system is composed of sensor nodes to monitor events around oven, and transmit sensory data to a computing unit. The system proactively reacts to hazards in order to prevent cooking associated risks. Figure 2 illustrates the hardware architecture of the cooking-safe system and Figure 1 presents its arrangement in real-world cooking environment.

Figure 1: Arrangement of the cooking-safe system in the kitchen.

6.1 Sensor Selection

The selection of sensors is based on the results of our risk analysis (Section 5). Each sensor is selected to monitor one of the identified parameters (The selected sensors are illustrated in Table 1). Our selection is also based on real-world integration requirements, which can be summarized as follows:

- **Integration requirements**: In order to integrate sensor nodes in the cooking environment, sensors must be non-intrusive. The selected sensor technologies (i.e., based on electrochemical, metal-oxide-semi-conductor, infrared, ultrasonic, and resistive hygrometer) do not require contact to operate, and can be installed around the cooking activity without interfering with user movement.
- **Practicability requirements**: Analogue output signals of the selected sensors are easy to acquire. For resistive and metal-oxide-semi-conductor sensors, resistance variations are

translated to voltage. For electrochemical sensors electric current is transformed into voltage, which can be easily interfaced with microcontrollers.

In addition, there are other factors that motivate our selection of sensors (e.g., price and appropriate response time).

6.2 Sensor Electrical Feeding

The selected sensors require different electric feeding voltages, so a "feeding board" is designed to meet this requirement (illustrated in Figure 2). Electrical power is taken from the sector through a transformer, which delivers 12V/1A as output. The four required electrical voltages (2.4V, 3.3V, 5V, and 6V) are obtained due to power regulators.

6.3 Microcontroller

The selected microcontroller is MSP430 by Texas Instruments, because it has the following features: Analog to Digital Conversion (ADC), multiple input/output, and two communication ports (UART, I2C or SPI).

Sensory data is transmitted through cables ADC (5) and I2C (1), from sensor nodes to MSP430 microcontroller via the feeding board and then from the MSP430 microcontroller to the computing unit by one serial frame. The frame is routed to the computing unit via the cp2101 module, which converts serial frame to USB frame. The composition of the frame is illustrated in Figure 3. Since environment variations are slow, the sampling period is one second. The frame is composed of the following attributes: ambient temperature, burner temperature, utensil temperature, relative humidity, distance between presence detection sensor and utensil (used to determine whether utensil is on burner or not), CO concentration, VOC concentration, and Alcohol concentration.

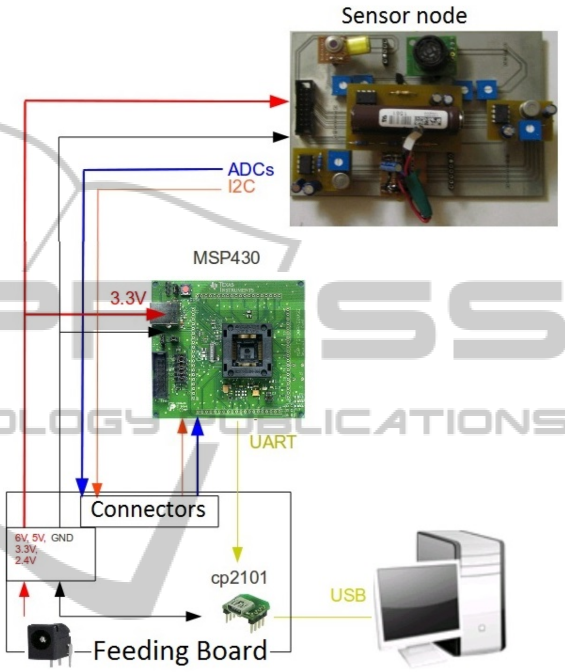

Figure 2: Hardware architecture of the cooking-safe system.

Table 1: Summary of the selected sensors and their technical specifications.

Sensor	Monitored information	Technology	Unit	Operating voltage	Power consumption	Response Time
Melexis MLX 90614	Ambient temperature and object temperature	Thermopile and infrared	(°C)	V_{cc} = 3.3 V	3 mW	100ms
SRF02	Object presence	Ultrasonic	cm	V_{cc} = 5 V		72ms
Honeywell H1H1 5030	Humidity	Resistive	% RH	V_{cc} = 3.3 V	1.65 mW	5s
Figaro TGS 5042	CO Carbone Monoxide	Electro-chemical	ppm			60s
Figaro TGS 2620	Alcohol	Metal-Oxide semi-conductor	ppm	V_h = V_{ref}= 5V	210 mW	20s
e2V MICS 5521	Volatile Organic Compounds (VOC)	Metal-Oxide semi-conductor	ppm	V_h =V_{ref}= 3.3V	80 mW	10s

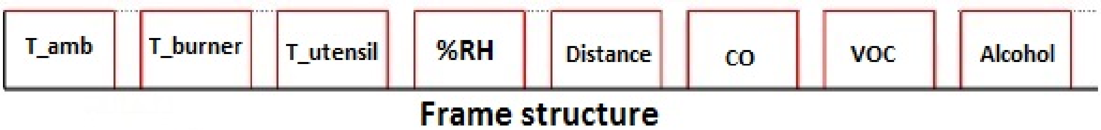

Figure 3: Frame composed of sensory data from MSP430 to computing unit via serial port.

6.4 System Building

The cooking-safe system experimental kit has been built based on the following properties and features:

- **Flexibility**: possibility of adding new sensors if required. The sensor node is designed such that adding/removing sensors is easily performed.
- **Simple physical installation**: The sensors are integrated on a node such that the node can be placed in an alternative location if required. However in this case, longer cables and appropriate sensor direction (for presence detection sensor (SRF02) and temperature sensor (MLX90614)) are required.
- **Non-intrusiveness**: as the oven surface is free and the components of the system are placed in adequate positions to monitor hazards and prevent risk situations. However, for the experimentation purpose two sensors are placed in the workspace in addition to the microcontroller and a computing unit.

6.5 Sensors Positioning

The output voltage of a sensor varies according to its position. Therefore, an appropriate sensor positioning around the oven is required, to acquire precise sensor measurements and to satisfy the integration constraints presented in subsection 6.4, we investigated several configurations and following is our solution (Figure 4, Figure 5): We placed on the oven hood level as illustrated in Figure 5 the following sensors: humidity sensor (H1H-5030), VOC sensor (MICS5521), Alcohol sensor (TGS2620), CO sensor (TGS5042), and temperature sensor (MLX90614) to measure burner temperature. We placed on the workspace as illustrated in Figure 4 the following sensors: presence detection sensor

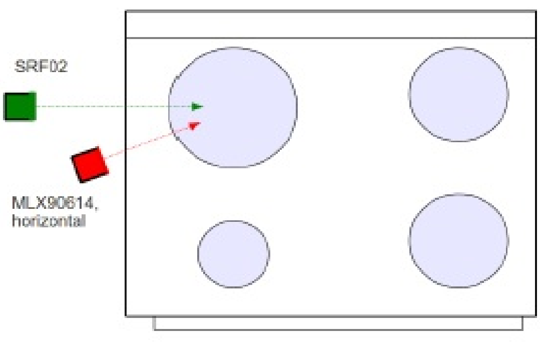

Figure 4: Positioning on workspace (20 cm to the left side of burner) of SRF02 sensor for detecting presence of utensil on burner and MLX90614 sensor for measuring utensil temperature.

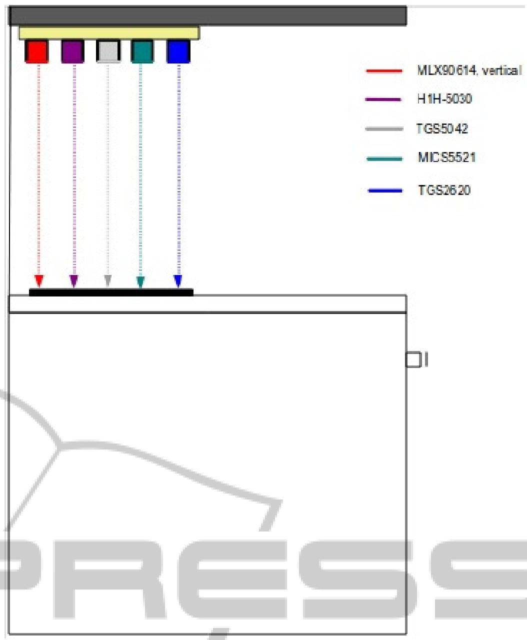

Figure 5: Positioning of sensors on level of oven hood. The temperature sensor MLX90614 is to measuring burner temperature.

(SRF02) for detecting presence of utensil on burner and temperature sensor (MLX90614) to measure utensil temperature.

This positioning configuration is non-intrusive as possible, in order not to disturb user movement and cooking habits. In addition, positioning sensors at the level of oven hood allows adequately monitoring the required parameters.

In addition, the distance between oven hood and cooking utensils is adequate for acquiring precise measurements from sensors based on the results of test for each sensor (Section 7). The motivation behind positioning SRF02 on workspace for detecting presence of utensil on burner is that the distance (20 cm) is appropriate for this sensor measurements and the positioning on workspace can avoid cooking heat if it is placed on the level of oven hood. We placed MLX90614 sensor on workspace for measuring utensil temperature (20 cm to the left side of burner) because of the low infrared emissivity of utensil's metal which obstructs its temperature measurment.

7 SYSTEM TESTING

A series of tests has been performed for each selected sensor. The objective is to investigate the behavior of each sensor in real world, and thus determine its limitations. To illustrate the importance of the test let examine the following cases. Temperature, humidity, and gases change frequently around the oven. Furthermore, there is no single method of cooking in real-world. These factors may affect sensing data (e.g., putting a small utensil on a large burner, may affect the measurements of the presence detection sensor). Thus, various cooking behaviors have to be considered to obtain correct and precise measurements. Measurements of sensors are also affected by the position and orientation of sensors (e.g., the temperature sensor does not give the exact temperature if placed far from the monitored object).

7.1 Test Settings

The first test series was performed using one burner of the oven, using neither ventilation nor light above the oven because prior experiments revealed that sensory date are changing with oven ventilation and/or light. Utensils used are: saucepan, kettle (brilliant metal), pan (opaque metal) illustrated in Figure 6, for this series of the tests.

Figure 6: Cooking utensils used for testing sensors.

The saucepan is smaller than the burner in order to study non-ideal situations. These cooking tools are selected to study the infrared emissivity between different metals, and explain different behaviors of an infrared sensor. We also experiment cooking several kinds of food: fish, meat, onion, peppers, and spaghetti. Also, we experiment heated oil (50ml of canola oil) in a frying pan for 8 minutes until oil starts to shudder.

7.2 Test Results

Following we present the results of tests performed on the selected sensors.

7.2.1 Results of VOC and Alcohol Sensors

We illustrate in Figure 7 the distinct boundaries between normal and risk situations according to output voltages of the VOC and Alcohol sensors, while cooking several kinds of food. The output voltages of VOC and Alcohol sensors in normal situations are as follows:

- In case of cooking hotdogs in a frying pan (Figure 8), the maximal output voltages for normal situation are around 1500 mV.
- In case of cooking fish, onion and peppers in a frying pan (Figure 9), the maximal output voltages for normal situation are near 1000 mV.
- In case of heating oil in a frying pan (e.g., for 8 minutes) (Figure 10), the maximal output voltages for normal situation are near 2000 mV because heated oil releases more VOC and Alcohol in the cooking smoke compared to cooking red meat, which releases more VOC and Alcohol than cooking fish and vegetables.

Therefore, output voltages of VOC and Alcohol sensors allow determining fire risk. If output voltages are greater than 2000 mV, then there is a potential fire risk.

7.2.2 Results of Presence Detection Sensor

SRF02 is an ultrasonic sensor used to detect presence of utensil on burner, based on measuring the distance between the sensor and the utensil. Sonar wave propagation depends on the propagation medium, so air variable conditions affect wave propagation. Ultrasonic sensor must compensate these effects in a variable environment. However, this sensor does not integrate such compensations. So, it has to be placed where the air is the most stable as possible; otherwise measurements will not

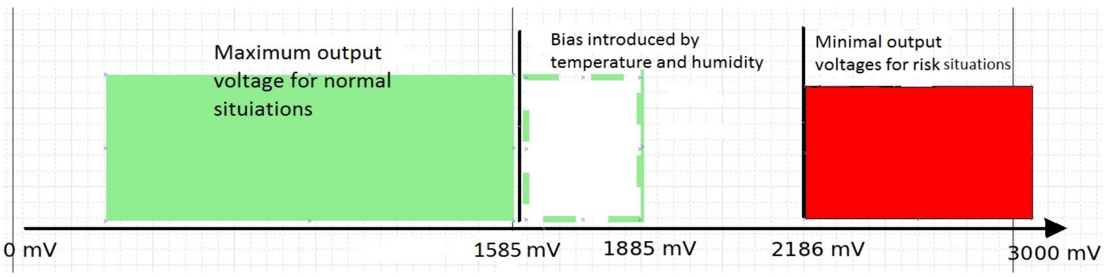

Figure 7: Output voltages of Alcohol (TGS2620) and VOC (MICS5521) sensors in normal and risk situations.

be precise. We excluded certain places such as the oven hood (hot air, cooking gases, and evaporated water) and the control panel because the temperature will be very high. Therefore; we positioned the presence sensor on the workspace around 20 cm to the left of the burner as illustrated in Figure 11.

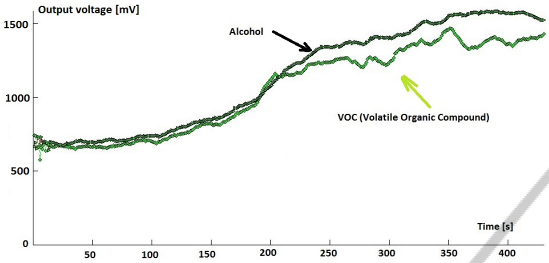

Figure 8: Output voltages of MICS5521 VOC and TGS2620 Alcohol sensors when cooking hotdogs in a frying pan.

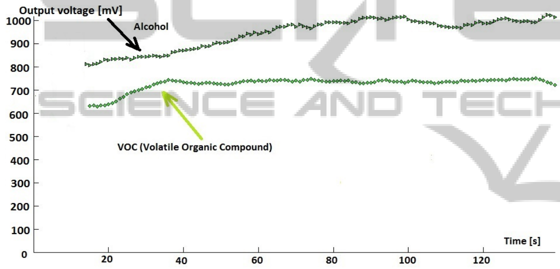

Figure 9: Output voltages of MICS5521 VOC and TGS2620 Alcohol sensors when cooking fish in a frying pan.

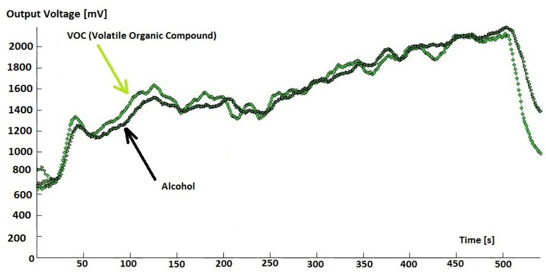

Figure 10: Output voltages of MICS5521 VOC and TGS2620 Alcohol sensors when frying oil during 8 minutes.

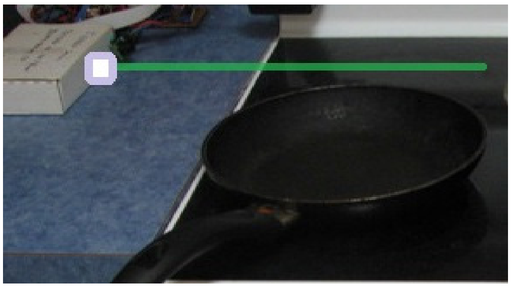

Figure 11: SRF02 sensor horizontal position.

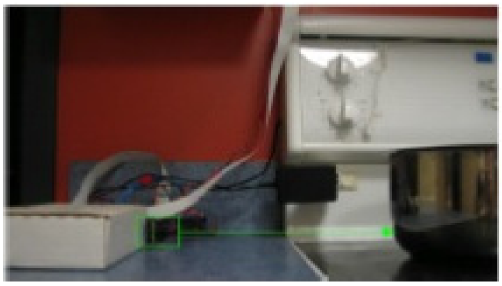

Figure 12: SRF02 sensor vertical position (2 cm) above workspace.

We found that the appropriate vertical positioning of the SRF02 sensor is around 2 cm above workspace (Figure 12). This vertical location allows detecting the presence of utensils with little height, like frying pan. If the sensor is vertically located lower than 2 cm then parasite may affect its measurements.

We tested SRF02 sensor by changing oven state (on/off), utensil type, utensil volume, and position of cooking utensil on burner. The goal of changing the position of cooking utensil on burner is to study the effect of heat on distance measurement. Figure 13 shows 7 different positions of the center of utensil. A series of measurements was performed, and yielded the following results:

- The very low position of the sensor is appropriate because this does not cause reflections. However; it must be horizontally oriented.
- To maintain the stable state of the sensor, a carton box covered it. Without these precautions, parasitic reflections appear.
- The measured values would be aberrant, if a cooking utensil was placed further than 30 cm from the sensor.
- The experimental results show that the form and volume of a cooking utensil has no impact on distance measurement using SRF02 ultrasonic sensor.

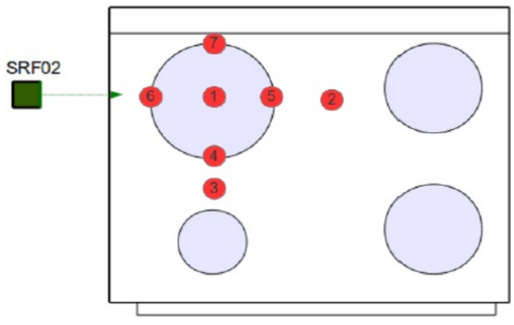

Figure 13: Positions of the center of utensil on burner for testing SRF02 sensor.

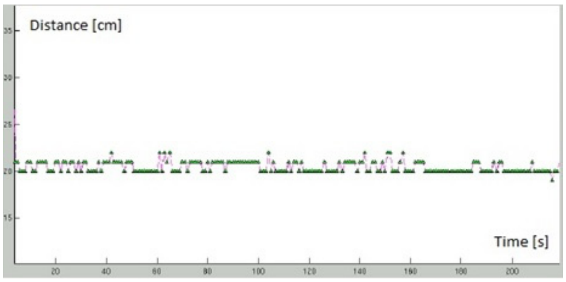

Figure 14: Distance measurements [cm] by SRF02 sensor while cooking meat in a frying pan placed in the middle of burner.

The obtained results prove that ultrasonic wave propagation varies with surrounding air temperature. Each time there is hot air between sensor and object, the measurements becomes less reliable. This is the case when the cooking utensil is not placed in the center of burner, or the case when the cooking utensil is smaller than the burner. Figure 14 shows distance measurements while cooking meat in a frying pan which is larger than the burner and placed in its center. The flow of hot air between the sensor and the pan is minimal and hence measurements of distance are reliable. Figure 15 shows variable distance measurements while heating water in the saucepan which is smaller than burner and placed in its center. The reason for unreliable measurements is that the exterior of the burner heats the surrounding air between the sensor and the cooking utensil.

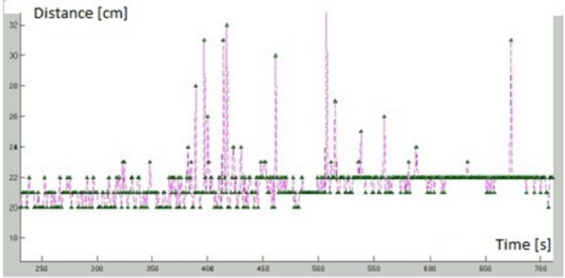

Figure 15: Distance measurements [cm] by SRF02 sensor while heating water in a saucepan placed in the middle of burner.

The previous results reveal that it is possible to detect that an object is on burner. Variations in distance measurements according to the position of utensil allow us to determine a confidence zone, such that, if an object is placed in the interior of this zone, it is considered to be on the burner. The confidence zone is illustrated in Figure 16 and Figure 17.

Detecting that an object is on burner is performed by comparing the distance returned by the sensor with threshold values.

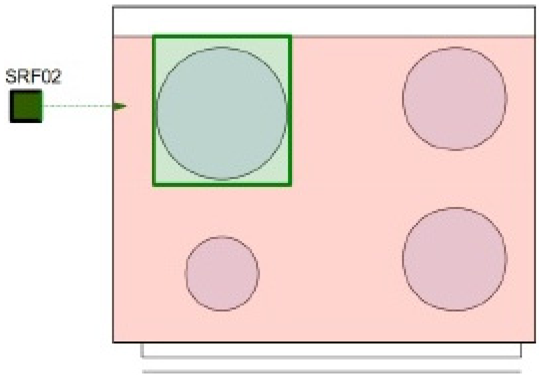

Figure 16: The ideal situation: if utensil is located inside the rectangle (green zone), then it is on burner, otherwise (pink zone) it is not.

7.2.3 Results of Humidity Sensor

As described in the sensors positioning section, humidity sensor is placed at the oven hood's level. Steam is transported by the smoke released while cooking process. The smoke rises up towards the oven hood.

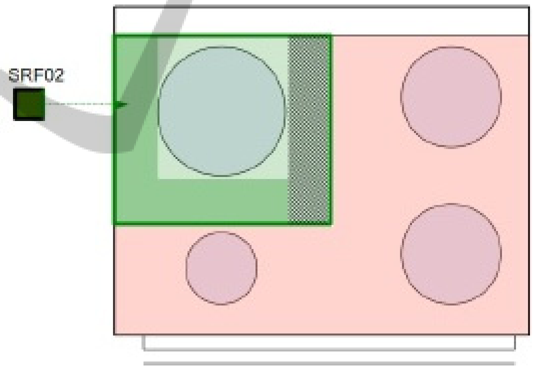

Figure 17: The actual situation: the inner rectangle (light green zone) represents the real "on-burner" zone. A utensil inside this zone is detected by SRF02. The outer rectangle (dark green) zone represents the false positive zone of SRF02 sensor where a utensil is detected as "on-burner" and in reality it is outside burner. The shaded zone represents the dead zone of the sensor.

This series of tests focuses on heating water using kettle, saucepan, and saucepan with lid. The experiments were performed with a cooking utensil half-filled with water. Figure 18 illustrates the obtained results.

As expected, variations in humidity depend on the quantity of steam released. While a lid covers the saucepan, steam cannot be ejected. The hygrometer starts and reacts immediately when steam is ejected. The saucepan without a lid carries more knowledge about boiling phenomena. Before water simmers, we

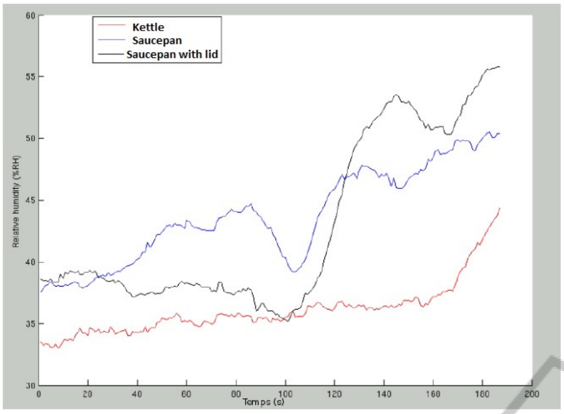

Figure 18: Relative humidity when water boils in: kettle, saucepan, and saucepan with lid.

observe increment in relative humidity %RH, which means that a small quantity of steam is released. This indicates an object is heated on a burner. Then, another increment of 5%RH indicates that water is simmering so the global water temperature is around 100°C. It is important to notice the difference in water temperature on the surface and in the bottom of the saucepan. When steam is released, the temperature of water molecules in the bottom of the utensil becomes around 100°C, and these molecules rise to the surface. The temperature of molecules on the surface is lower. Therefore, rapid variation in the humidity is an important indicator of water temperature in a cooking utensil.

To conclude, previous tests show that it is feasible to prevent splash burn risk based on relative humidity, because it does not change significantly unless a liquid is being heated. Tests also revealed that there are clear thresholds which enables to separate between normal and risk situations. Therefore, an algorithm of splash burn prevention can be established.

7.2.4 Results of Temperature Sensor

Hot objects during cooking are utensils and burner. We performed 12 experimentations to measure the temperature of cooking utensils when water boils: three with a kettle, three with a frying pan, and six with a saucepan. In addition, we investigated dangerous situations by heating empty frying pan and saucepan. These experiments cover the majority of daily cooking situations. The motivation behind experimenting with boiled water is to overcome the measurements imprecision of the infrared sensor used to measure the temperature of cooking equipment since water boils at a known temperature (100°C). The results are presented in Table 2.

Table 2: Experimental results of the measured utensil temperature when water boils.

Utensil	Experiment configuration	°C
Kettle	middle of burner	40°C
Frying pan	middle of burner	65°C
Saucepan	Bottom left corner of burner	58°C
	Middle of burner of burner	80°C
	Up right corner of burner	110°C
Saucepan, Frying pan Kettle	All utensils in the middle of burner, which is preheated.	111°C 67°C 45°C
Frying pan Kettle Saucepan	All utensils are placed in the middle of burner and heated **empty** (hazard situation) during 5 minutes.	113°C 69°C 100°C
Saucepan	Bottom left corner of burner	64°C
Saucepan	Up right corner of burner	150°C

The imprecisions in measurement of utensil temperature are due to the low infrared emissivity of metals and to the heat of cooking that disturb the measurements of this infrared sensor.

8 CONCLUSIONS

Enabling kitchen safety is a major factor in independent living for ageing people. We present in this paper our cooking-safe system and illustrated in details the selected sensors that constitute the basic building block of the system. We have started building the system by performing an insightful cooking risk analysis and assessment. As a result, we identified the major risks during cooking as: fire, burn (by contact or splash), and intoxication (by gas or smoke). We also presented this paper our experimental study to determine the pertinent parameters to monitor in order to prevent the three major risks. As results the parameters are: the concentration of VOC, Alcohol, CO gases in the cooking smoke, ambient temperature, temperature of utensil, temperature of burner, relative humidity, and presence of an object on burner. In addition, we presented the significant experimental results used to select the appropriate sensors to measure the pertinent parameters. The presented results are the foundation of our work on designing algorithms to prevent fire, burn, and intoxication by gas/smoke risks, which will be presented in other papers.

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