October 22, 2015

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440W – Functional Specification for an Automated Cooking System

Dear Dr. Rawicz,

Enclosed is a document regarding the functional specification for the SmartChef system. We are designing a home automated cooking system that can prepare meals with fresh ingredients to facilitate lives of the physically disabled. Our ultimate goal is to enable those who are physically impaired to self-prepare meals using nutritious ingredients, providing them an additional degree of independence in their daily lifestyle.

Our functional specification provides a description of the high-level requirements of our system. It also discusses the testing methodology that will be used. This document will later be used as a guide for the design and development of our device.

The SmartChef team is comprised of four senior engineering students with a broad range of skills and specialties. If you have any questions or comments regarding our functional specification or product, please contact me at cyh12@sfu.ca. Alternatively, you may contact me by phone at (778) 688-6157.

Sincerely,

Christine Huang
Chief Executive Officer
SmartChef

Enclosure: Functional Specification for an Automated Cooking System

SMART CHEF

Functional Specification for the
SmartChef Automated Cooking System

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Executive Summary

Physical impairment is a prevalent issue that affects individuals worldwide. Everyday tasks that are seemingly easy for the able-bodied population present unremitting obstacles for those who are physically disabled. While many home automation solutions already exist, we want to push these limits and further improve the quality of life for the disabled. We want to provide them with an additional degree of independence, regardless of their impairment.

In an aging population such as Canada, it is important to implement solutions for assisted living that eliminate the burden of home care services. Presently, a vast amount of home automation technologies exist. They encompass simple devices such as wireless remotes that control home appliances or lights, and can range to more complex solutions such as emergency assistance systems. Despite such a diverse scope of technologies, one area that is notably overlooked is kitchen automation in domestic environments. While a number of automated kitchen devices currently exist, they are costly, and are generally tailored towards industrial food applications. This is where the SmartChef seeks to fill the void.

The SmartChef is a home automated cooking system that prepares meals using fresh ingredients with the simple push of a button. Located anywhere at home, a physically impaired individual will have access to a remote that can activate the cooking system just by pushing a button. The SmartChef will consist of many features specifically chosen to ensure that our product will be a valuable utility for the physically disabled. The critical requirements essential to the functionality of our product are:

- The ability to dispense ingredients onto a pan
- The ability to move the pan over to a heating element where the ingredients will be cooked
- The ability to stir the ingredients while heating
- The ability to control the timing of each subcomponent of the system to ensure ingredients are not over/under cooked

The non-critical feature of our product includes:

- The ability to automate a mechanism that serves the meal onto a plate

As safety and reliability are inherent attributes to the SmartChef team, standards and guidelines from the CSA will be adhered to in addition to the functional requirements.

The design and implementation of the aforementioned features and procedures will be accomplished with an expected date of completion of December 1, 2015.

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Glossary

CLS	Control line signal
CSA	Canadian Standards Association
GUI	Graphical user interface
ICS	International Classification for Standards
MCU	Main control unit
PVC	Polyvinyl chloride
PWM	Pulse width modulation
RPM	Revolutions per minute
SCC	Standards Council of Canada
T_M	Motor torque

1. Introduction

The SmartChef is a home automated cooking system aimed to assist the physically disabled by helping them regain a more independent lifestyle. The main objective of the system is to prepare rudimentary meals with limited human interaction. The SmartChef system includes four distinct processes: dispensing ingredients, heating and mixing the ingredients, and finally serving the meal onto a plate. We strive to create an effective and safe product, such that it is appropriate for domestic use with little risk to the customer. Thus in addition to the aforementioned functions, our system includes safety mechanisms should the system fail during runtime. The requirements for the automated cooking system, as proposed by the SmartChef team, are described in this functional specification.

1.1 Scope

This document describes the functional requirements of the SmartChef that must be met during its development cycle. These requirements will serve as a basis for a proof-of-concept model and describe the required functionality for the production model. The listed requirements will be used during the design and testing stages of the SmartChef system, though minor adjustments may be needed during development or after testing.

1.2 Intended Audience

The functional specification document is intended to be used by the members of the SmartChef team throughout the design and testing stages. Additionally, engineering teams shall use this to determine the progress of the project throughout the development cycle. Finally, it shall be used by test engineers to demonstrate that the system works to the required functionality as mentioned in this document.

1.3 Classification of Requirements

The following convention will be used throughout this document differentiate between the categories of functional requirements:

[Rn-p] Functional requirement

where n represents the functional requirement number and p represents the priority of the functional requirement.

Priority of the functional requirement is shown below:

i. The requirement applies to the proof-of-concept system only
ii. The requirement applies to both the proof-of-concept system and final production
iii. The requirement applies to the final production only

2. System Requirements

The general requirements applicable to the SmartChef system are presented in this section.

2.1 System Overview

The SmartChef solution is a system that will automatically do the tedious and time-consuming work of cooking with the push of a button for physically impaired consumers. The top-level design overview of our model is shown in the diagram below.

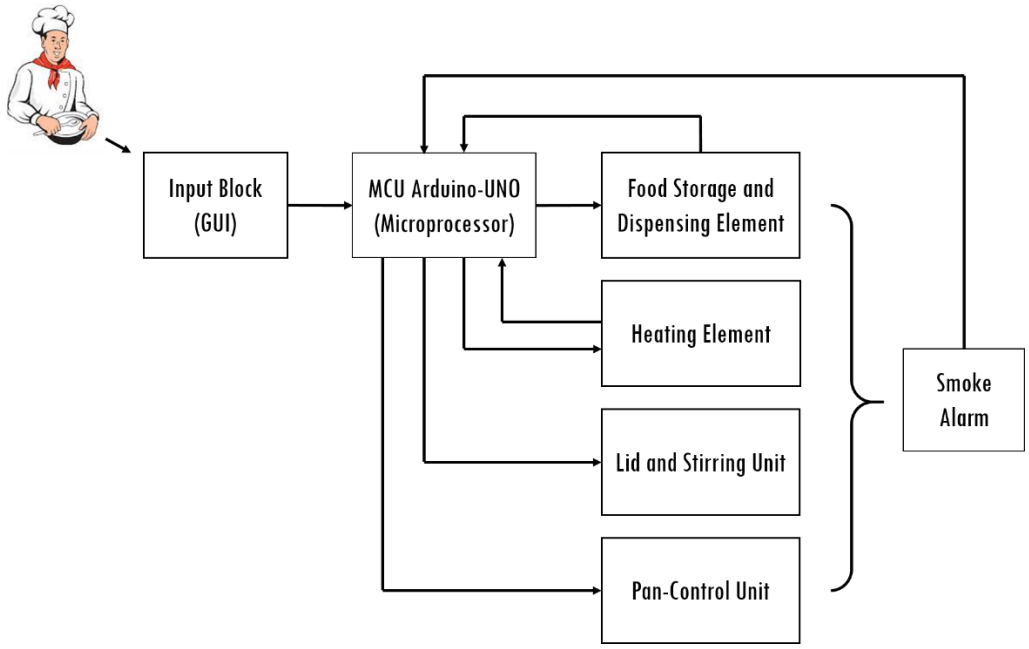

Figure 1: Top level system design overview

As shown in the diagram, the system will be triggered with an input through a graphical user interface (GUI) that will initiate the process of sequential operation of servomotors that will drive the control system. Upon selecting the food item of choice by the user, the input will be passed to the Arduino processor that will run the mapped program stored in its memory. The precise control of the angular speed, direction and timing of the motors will be driven by a control line signal (CLS) handled by the program in the Arduino processor as a main control unit (MCU). This feature enables flexibility for any new SmartChef programmers to write their own recipe script within the specified functional specification to cook new items in the future.

The automated electromechanical system is divided up into five different control units that are dependent on each other. Some units will have some level of a dynamic feedback control system dedicated to maintain the safety of SmartChef consumers at all times.

2.2 General Requirements

[R1-ii] Each subsystem will have a manual and automatic control for each function detailed below:

- [R1a-ii] Specific dispensing of two liquid ingredients, and four solid ingredients
- [R1b-ii] Motion of pan from the dispensing area (Area 1) to a heating and stirring area (Area 2)
- [R1c-ii] Heating ingredients by enabling the heating element
- [R1d-ii] Stirring the contents of the pan
- [R1e-ii] Motion of pan from the dispensing area to a serving area

[R2-ii] Manual control of the system will consist of an individual button or dial

[R3-ii] Automatic control will consist of a series of pre-programmed commands issued by the microcontroller

[R4-iii] Consumers can control the system through a smartphone application over Wi-Fi

2.3 Physical Requirements

[R5-ii] A control box will mount each manual control and enclose circuitry

[R6-ii] A static frame will securely mount each subsystem in a non-conflicting manner

[R7-ii] The total assembly should be less than 50lbs

[R8-ii] The total assembly should fit on a 1m x 1m table

2.4 Safety Requirements

[R9-i] The system will cease to operate in case of malfunction during runtime

[R10-iii] For prolonged use, ingredients will be stored in a refrigerated area at a temperature below 4° C [10]

[R11-iii] In case of fire or malfunction, consumers will be alerted by a smoke detector

2.5 Standards

For a household cooking device, it is crucial to meet the regulations for electrical, fire, general safety, and environmental impact. Stated from the Canada Consumer Product Safety Act: "*No manufacturer or importer shall manufacture, import, advertise or sell a consumer product that (a) is a danger to human health or safety ...*" [8]. Our product poses high risk if it is poorly designed. Therefore, to ensure our product meets a reliable level of safety and quality, we have decided to adhere to the standards administered by the Canadian Standards Association (CSA). The CSA is accredited as a standard developing organization by the Standards Council of Canada (SCC) in the areas of relevance to our product: Domestic electrical appliances in general, domestic refrigerating appliances, plant and equipment for the food industry. Products of these nature are regulated by the CSA with respect to International Classification for Standards (ICS) number 97.040.XX [8]. Standards from this series pertain to household kitchen appliances, including high-power electronics such as ovens. Our strategy for adherence to these standards is to use CSA certified parts such as relays, power supplies, heating elements, motors, and

controls. In this phase of the design, we do not have access to the CSA document listing specific criteria to adhere to this standard. In the production phase of our product, we would invest in a document and begin the efforts to become accredited.

3. Food Storage and Delivery Unit Requirements

This unit consists of motors consuming less than 15 Watts of power during the dispensing cycle. The system should be designed in such a way to deliver two different food items with the use of one motor, which generates a system capable of dispensing four different food items using two motors. Additionally, there will also be a motor dedicated to dispensing water and oil during the cooking period. The food items will be stored in non-reactive polyvinyl chloride (PVC) cylindrical containers that can breathe just the right amount, making it an ideal food grade storage element [9]. The entire dispensing element is separated away from the heating element with a non-flammable surface. Table 1 includes the types of ingredients that will potentially be used during cooking with the corresponding constraint for each ingredient.

Table 1: Potential ingredients with corresponding constraints

Ingredient	Quantization	Viscosity	Refrigeration
Eggs	1 egg	Slow fluid	Yes
Rice	½ cup	Solid	Yes
Beans	½ cup	Solid	Yes
Chopped Peppers	½ cup	Solid	Yes
Cooking Oil	1 tbsp	Liquid	No
Water	1 tbsp	Liquid	No
Flour	¼ cup	Powder	No
Chopped Whitefish	¼ cup	Solid/Liquid	Yes
Chopped Chicken	¼ cup	Solid/Liquid	Yes
Tofu	¼ cup	Solid/Liquid	Yes
Spices	1 tsp	Powder	No
Chopped Tomato	½ cup	Solid/Liquid	Yes

3.1 General Requirements

[R12-i] Every rotation of the motor that dispenses food onto the pan should be recorded in a counter variable that must be fed to the heating element unit

[R13-i] The amount of food dispensed must match the user's input selection

[R14-ii] The dispensing of the liquid must be conducted with the use of controlled valves without any leakage

[R15-iii] The food dispensing mechanism should be efficient in terms of power consumption by the motors (ie. the system should deliver at least two food items per motor)

3.2 Physical Requirements

[R16-i] The food storage containers must be of food grade category that is nontoxic and should not react with the food items over long periods of time

[R17-i] All the electrical components must be enclosed with a non-conductive material

[R18-iii] The unit must look well organized with excellent clarity of the containers that are puncture resistant and cling [4]

[R19-iii] Each cycle of the motor must deliver at least 14 $inch^3$ of food material in the pan

3.3 Electrical Requirements

[R20-i] The motors must be supplied with an external power source of 5V with a current limiter of 1.5A with the load

[R21-i] The motors must be compliant to the specifications mentioned in section 0

3.4 Safety Requirements

[R22-i] All motors must stop immediately and be in a non-dispensing state of angular position during time of emergency

[R23-i] The system must have a manual circuit breaker element with a “Switch Off” button that can be used anytime during emergency

[R24-ii] The food containers must not exceed room temperature (21˚C)

[R25-iii] All elements of the unit that are hazardous to the SmartChef consumer must be clearly labelled

[R26-iii] All food storage containers must be washed with detergent to ensure proper sanitation of the unit

4. Stirring Unit Requirements

The main purpose of the stirring mechanism is to thoroughly mix the ingredients in the pan while it’s over the heating element to ensure they don’t stick to the cooking utensil. The stirring unit will be covered with a lid to protect food from falling out of the pan. Furthermore, the stirring mechanism will be lifted up and down with the lid so that the cooking pan can be removed from the heating element should the addition of ingredients be required.

4.1 General Requirements

[R27-ii] The stirring mechanism must rotate at a constant 20 RPM or less

[R28-ii] The stirring mechanism must be secured and rotated around the center of gravity of the unit for smooth motion

[R29-ii] The stirring mechanism must be able to withstand high temperatures

[R30-ii] The stirring mechanism must be removable for cleaning

4.2 Physical Requirements

[R31-ii] The stirring mechanism must move up, leaving at least 50mm of clearance between the pan and the stirring unit

[R32-ii] The motors must stay synchronized throughout different motions (ie. One motor maintains a vertical linear motion of the stirring unit while another is rotating it)

[R33-ii] The lid of the stirring unit will enclose the entire pan while in use to ensure that ingredients are not spilled

4.3 Electrical Requirements

[R34-ii] The motors must be compliant to the specifications mentioned in section 0

4.4 Safety Requirements

[R35-i] All motors must stop immediately and be in a non-dispensing state of angular position during time of emergency

[R36-ii] The stirring unit will not have sharp edges, allowing it to be safe for the user to touch when the system is off

[R37-ii] The electrical components will be completely isolated from any metallic parts of the stirring unit

[R38-ii] The stirring unit will not touch any flammable materials while in use

5. Pan-Control Requirements

To ensure that the SmartChef is a safe system, a pan containing the ingredients will be moved back and forth between the heating unit and the area where the ingredients are dispensed. Should food items or even oil be spilled while being dispensed, they will be isolated from the heating element. Figure 2 demonstrates the motion of the pan between the heating and food-dispensing units.

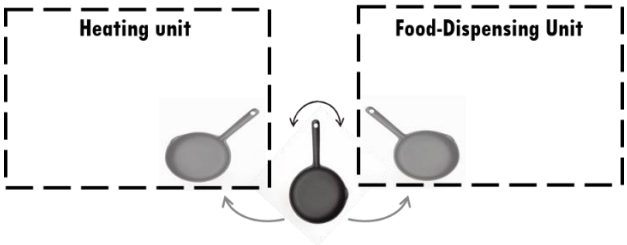

Figure 2: Movement of the cooking pan between the heating and food-dispensing units

In addition to the aforementioned controlling of the pan, it will also be automated in such a way that it will serve the final meal onto a dish for consumers. The requirements for the pan-automated mechanisms are listed in the following sub-sections.

5.1 General Requirements

[R39-ii] The cooking pan will move between the heating and food-dispensing units when required
[R40-ii] The pan will be automated so that it serves the final meal onto a dish
[R41-iii] The pan can be easily removed from the system for cleaning

5.2 Physical Requirements

[R42-ii] The pan will rest on a surface at all times to minimize the load on the motor that is responsible for controlling the motion
[R43-ii] The weight of the pan containing ingredients will not exceed 3.5 kg [7]
[R44-ii] The diameter of the pan will not exceed 25 cm
[R45-ii] The handle of the pan will not exceed 25 cm

5.3 Electrical Requirements

[R46-ii] The motors must be compliant to the specifications mentioned in section 0

5.4 Safety Requirements

[R47-i] All motors must stop immediately and be in a non-dispensing state of angular position should a malfunction occur
[R48-ii] The pan will be completely contained within the system (ie. not protruding off the edge of the surface) to minimize the risk of burn related injuries
[R49-ii] The motors and their electrical components will be completely isolated from the heating element of the system

6. Heating Element Requirements

The heating unit in the system will operate in a similar manner as conventional kitchen stoves. The requirements for this element are listed in the following subsections.

6.1 General Requirements

[R50-ii] The heating element will controllably reach a cooking temperature range up to 300°C [1]
[R51-ii] The heating unit can be manually switched off [1]

6.2 Safety Requirements

[R52-ii] The heating area enclosure will be constructed from a non-flammable, low heat-conductance material (such as fiberboard)

7. Processor Module Requirements

This will be the base software entity that will build the MCU to handle overall operation of the entire electromechanical control system. The processor will be connected to the GUI from where it will receive different inputs from the user. The processor used in this project is an open source Arduino – UNO development board [2] that is commonly available for academic projects. This microprocessor communicates and is compliant to the original STK500 protocol for uploading recipe programs [3].

The maximum voltage that Arduino can provide is limited to 5V, which is not sufficient enough to drive the motors. Thus, an external power supply is required. All the servomotors from different control units and the processor will share a common ground. The available digital pins/PWM pins on the processor board are assigned to each motor in different control units to handle the CLS delivery requirement. The processor will monitor the phase of the overall cooking procedure with timing parameters and the angular positions of the motors. When the smoke alarm is triggered, the processor will immediately shut down the food delivery mechanism and turn off the heating element. Furthermore, the program should also be able to dynamically allocate the need of changing different functions as required if any interruption occurs during the cooking procedure. The software solution of approaching the problem is to allow development flexibility for new item recipes and to avoid external hardware programming. Figure 3 below shows a general schematic of the Arduino and servo motors that will be utilized in our system.

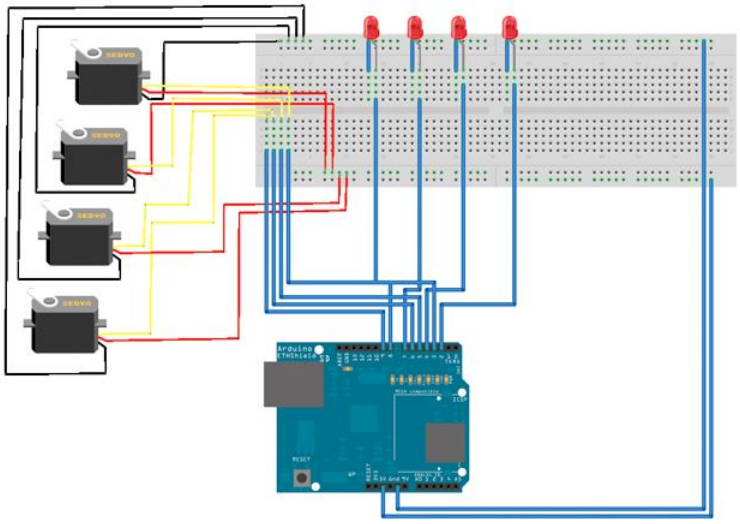

Figure 3: General schematic of the servo motor circuit with Arduino-UNO without external power source [6]

7.1 General Requirements

[R53-i] The processor must have sufficient memory to store recipe programs written by SmartChef engineers

[R54-i] The processor must be powered in a voltage range of 5-12V. Using lower voltage than the specified range might cause instability in the system. Using a higher voltage will result in the heating of the voltage regulator of the processor board

[R55-i] The processor must have a circuit breaker functionality connected to all the units in order to immediately halt the system in case of emergency

[R56-i] The processor should be able to provide the rotational data of the motors in order to analyze the transient response of the motors for performance analysis

[R57-i] The processor board should be enclosed in a waterproof box to avoid contact with food items during the process of cooking

[R58-ii] The processor must support the use of 8-bit PWM signal or a digital I/O as the CLS to control the servo motors

[R59-ii] Powering up the servo motors with the processor board should be avoided

[R60-ii] The processor must be able to handle multiple motors at the same time

[R61-iii] The processor board should contain an additional resettable polyfuse that protects a computer's USB ports from short and overcurrent [1]

8. Motor Requirements

As an automated system, motors are the fundamental part of our system which will do the work of moving and rotating any components to their specific location at the desired time. Given the scale of complexity in designing this automated system, servomotors provide a quick solution for our requirements. A more cost effective method of building the required motors could be achieved by attaching a control electronics unit with a DC motor and a potentiometer for feedback of the angular position of the motor shaft with gears [5]. Avoiding this simple design implementation may result in high costs paid to the manufacturers that produce functional servomotors. Nevertheless, the motors in our system will be controlled with a CLS sent from the MCU that records the timing and positional parameters of each motor.

The selection of the servomotors should be done with the constraints on the type of motor, speed of the motor, power rating and torque limit. For this project, a positional rotation servomotor with the output shaft rotating half a circle is adequate to handle all application requirements. The mass and the frictional coefficient of the block or any component that will be moved by the motor must result in torque under the limit of the motor's specified torque, T_M. The opposing force in the various units are different (ie. The controlling of the pan and the stirring unit will include force from the weight of the pan/lid, dispensing water/oil will include friction of the valve). Using the basic law of physics, we have:

$$Torque = rFsin\theta$$

where *r* is the distance between the point of load and the motor's axis of rotation, *F* is the force required to move the load, and θ is the angle between *r* and *F* (we will consider this to be 90°). The torque constraint from the motor that will be used in this project is: **T_M*: (Kg-cm/Oz-in): 9.6/133***. This means that the distance between the load and the force at the point of application must be under the provided limit of:

$$rFsin(\pi/2) \leq 9.6\ kg \cdot cm \qquad \text{*Efficiency of motor}$$

This will allow us with some flexibility in distance and the force from the load to remain within the limits of the T_M.

The motor should consume less than 10 Watts of power. By using 4-6V voltage potential, the current drawn from the motor can be analyzed as a variable with different load units connected. With the given power and voltage, the maximum limit of the current through the motor during work must be specified as the following:

$$I_{max} = \frac{Power\ Limit}{Specified\ Voltage\ Used}$$

The table below shows the limitations of the motor used in this development process.

Table 2: Detailed specifications of the motors used in the SmartChef system [7]

Parameters	Values
Control System	Pulse Width Control 1500usec Neutral
Required Pulse	3-5 Volt Peak to Peak Square Wave
Operating Voltage	4.8-6.0 Volts
Operating Temperature Range	-20 to +60° C
Operating Speed (4.8V)	0.24sec/60° at no load
Operating Speed (6.0V)	0.20sec/60° at no load
Stall Torque (4.8V)	106.93 oz/in. (7.7 kgcm)
Stall Torque (6.0V)	133.31 oz/in. (9.6 kgcm)
Operating Angle	45 Deg. one side pulse traveling 400 µsec
Direction	Clockwise/Pulse Traveling 1500 to 1900 µsec
Current Drain (4.8V)	8.8mA/idle and 350mA no load operating
Current Drain (6.0V)	9.1mA/idle and 450mA no load operating

The maximum electrical power consumed by the motor during operation with no load is given by:

$$P_{in} = I_{max} * V = 450mA * 6V = \mathbf{2.7\ Watts}$$

The maximum mechanical output power delivered during operation with no load is given by:

$$P_{out} = Torque * Angular\ Speed\ (rps)$$

Thus the motor efficiency is P_{out}/P_{in}. Considering the efficiency of the motor, all the units must not apply torque more than the percentage of efficiency times the stall torque of the motor.

8.1 General Requirements

[R62-ii] The organization of the motors must look neat which will contribute towards the overall aesthetics of the system

[R63-ii] The motors selected must be under $35

[R64-iii] The electromechanical design must be an efficient system by using less motors to produce maximum mechanical work

8.2 Physical Requirements

[R65-ii] The temperature of the motors must be below 40° C at all times during both operating and idle state

[R66-ii] Metal gears must have higher priority over plastic gears attached to the shaft of the motor

8.3 Electrical Requirements

[R67-ii] No motor should be applied with high force at the point of application generating torque that is greater than the stall torque of the motor

[R68-ii] The motors must be supplied with an external power source with a voltage range of 4-6V

[R69-iii] An external current limiter circuit must be used as an Overload Protection to stop the motor from drawing higher current than the specified I_{MAX}

8.4 Safety Requirements

[R70-ii] The employed motor for a particular application in the unit must be capable of handling the assigned task without any risk of fire, electric shock or personal injury [4]

[R71-ii] The positioning of the motor with the application must be designed in a fail-safe method to avoid any risk even if the motor fails to operate

[R72-iii] At all times, motors should be protected with external materials that are moisture resistant with low heat conducting capability

9. Relay Requirements

A relay will be utilized to control the heating element in the SmartChef system. The requirements are listed in the following subsections.

9.1 General Requirements

[R73-ii] The relay will be interfaced at microcontroller voltage level
[R74-ii] All AC power leads will be enclosed away from users
[R75-ii] Power to relay mechanisms will be provided by an external power supply defined in section 9.2

9.2 Electrical Requirements

[R76-ii] The DC power supply must provide enough current overhead to operate all motors in sequence
[R77-ii] All electronics components will be powered by a single AC socket compatible with 120V AC at 60Hz.

10. User Documentation

[R78-iii] The user manual must include a detailed setup guide with an introduction to the system.
[R79-iii] The user manual must have non-technical instructions which can be easily understood by users
[R80-iii] The user manual must include a website address with customer support and warranty information.
[R81-iii] A technical document must be created for technicians and vendors to help them fix any issues with system
[R82-iii] The user manual must be provided in English, French and other different languages for international markets

11. Sustainability & Safety

Sustainability for the SmartChef team means to provide long term solutions while keeping the impact on the environment to a minimal at the end of the product life. The engineers working on this home automated cooking system will choose electrical components that can be easily recycled. Any other material used in the process of building the system will also be selected keeping a cradle to cradle design in mind.

Safety is one of the main focuses while designing the SmartChef system. The production version of the system will have multiple heat and motion sensors at various locations so that system can be shut down in case of failure during runtime. The following requirements must be met by the system.

11.1 General Requirements

[R83-iii] The system must be able to withstand extreme usage for at least 10 years

[R84-iii] The system must include full information on the recycling of different components in the user document

[R85-iii] The system must have smoke detectors and heat sensors in case of fire

[R86-iii] All electrical and mechanical components must be securely and safely mounted such that they don't inflict any harm to the user

12. Conclusion

This document has presented the SmartChef system functions and the priorities under our constraints. This document serves as a guide to the development and implementation stages. Priority levels i and ii will be included as requirements for the prototype currently being developed. In brief, these are the dispensing, heating, serving, and stirring mechanisms, and the microcontroller firmware for sequencing these functionalities. Lower priority features are Wi-Fi compatibility, cleaning mechanisms, and dispensing unit modularization. This prioritization will allow us to develop the essential hardware framework for cooking a meal without spending excessive time machining sophisticated mechanisms, or overdeveloping the user-interface compared to the hardware functionality. The main focuses are the dispensing, heating, serving, and stirring mechanisms controlled by a single microcontroller, non-obstructive modularization of the cooking process, proper frame constructing, and power supplies. Each module is individually testable and independent, with safety addressed through standard adherence, fail-safe mechanisms, and hazard consideration. For our prototype, the SmartChef addresses sustainability by sourcing recycled materials when possible, and using household appliance materials with low-environmental impact. With these guidelines in place, we will be able to construct a prototype by December 2015.

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