UNIVERSITY OF CRETE
DEPARTMENT OF COMPUTER SCIENCE
FACULTY OF SCIENCES AND ENGINEERING

An Accessible Smart Kitchen Cupboard

by

Marios Gavaletakis

MSc dissertation submitted in partial fulfillment for the

Master of Science degree in Computer Science

Heraklion, June 2023

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APPROVED BY:

Author: Marios Gavaletakis

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Date: 2023.06.27 16:08:29 +03'00'

Supervisor: Constantine Stephanidis, Professor, University of Crete

Committee Member: Georgios Papagiannakis, Professor, University of Crete

Committee Member: Antona Margherita, Principal Researcher

Director of Graduate Studies: Polyvios Pratikakis, Associate Professor

Heraklion, June 2023

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my studies and pursue my dreams. I will be forever grateful for the sacrifices they made and for the love and support they have shown me. They are always in my heart and I am blessed to have them on my side.

Abstract

In a household, the kitchen holds immense significance among all rooms and is often considered the central hub, as it not only serves as a space for meal preparation and consumption, but also acts as a gathering spot for families and friends. It is where people come together to cook delightful meals, engage in conversations around the kitchen table, and carry out everyday activities. With the substantial amount of time spent in the kitchen, there arises a desire to discover intelligent methods to simplify and enhance daily routines. However, while it is expected that every home should provide comfort and safety for its residents, individuals with disabilities often encounter challenges with their kitchen cupboards, as these spaces fail to meet their everyday requirements. Various impairments, such as visual, motor and cognitive, pose significant difficulties even when attempting seemingly "simple" tasks in the kitchen. To address this issue, we present our solution: the "Accessible Smart Kitchen Cupboard," an accessible innovation designed to streamline inventory management and aid in the cooking process.

The Accessible Smart Kitchen Cupboard is a user-centric, inclusive prototype for kitchen storage, catering to a diverse range of users, such as adults, children, the elderly and individuals with disabilities. Designed with accessibility in mind, it incorporates advanced technologies and a multitude of sensors to gather detailed information about each stored food item, including its type, precise location, quantity and expiration date. The cupboard facilitates multimodal communication and employs a comprehensive array of input and output channels. Users have the flexibility to interact with the cupboard using either voice commands or a user-friendly touchscreen interface. In terms of output, the cupboard utilizes LED stripes to provide color-coded information,

delivers auditory responses, and utilizes various types of vibrations to convey relevant feedback to users.

The Smart Kitchen Cupboard encompasses a range of fundamental functionalities aimed at enhancing the user experience. These include: (a) assisting users in managing and organizing food items within available slots, simplifying the storage process; (b) seamless integration with the "AmI Chef" system, by providing valuable support and assistance throughout the cooking process; (c) supplying users with comprehensive information regarding the status and particulars of each stored product, including quantity levels and expiration dates; (d) promptly notifying users when the kitchen inventory requires replenishment, ensuring a well-stocked pantry. In general, its design prioritizes accessibility, allowing individuals with diverse physical or cognitive abilities to easily engage with and enjoy all of the aforementioned functions.

This thesis encompasses several key elements. Firstly, it explores the challenges and difficulties faced by kitchen users, both with and without disabilities, such as vision, hearing, mobility or age-related issues when assessing the status of their food stocks. Then, it comprehensively analyses existing smart kitchen cabinets and storage systems, with a particular emphasis on their limited accessibility features and their shortcomings in meeting the needs of users with diverse abilities. Next, it extensively describes the design and functional requirements of the Accessible Smart Kitchen Cupboard including a detailed overview of the components comprising the cupboard and their interconnections, all geared towards providing a seamless user experience and tailoring it to meet the specific requirements of different user groups. Finally, it reports the findings and valuable insights derived from a series of cognitive walkthrough experiments conducted with experts in

Human-Computer Interaction (HCI), contributing valuable knowledge and perspectives to the thesis, enhancing its overall validity and relevance.

Keywords: Smart cupboard, Intelligent cabinet, Ambient Intelligence; Intelligent Kitchen, Accessibility**;** Multimodality

Περίληψη

Η κουζίνα κατέχει εξέχουσα σημασία μέσα σε ένα νοικοκυριό και μπορεί να θεωρηθεί ως ένας κόμβος, καθώς δεν χρησιμεύει μόνο ως χώρος για την προετοιμασία και την κατανάλωση γευμάτων, αλλά λειτουργεί επίσης ως τόπος συγκέντρωσης της οικογένειας και φίλων. Είναι ο χώρος όπου οι άνθρωποι συναντιούνται για να μαγειρέψουν γεύματα, να συζητήσουν γύρω από το τραπέζι της κουζίνας και να πραγματοποιήσουν κάποιες καθημερινές δραστηριότητες. Με σημαντικό χρόνο να δαπανάται στην κουζίνα, προκύπτει η επιθυμία να ανακαλύψουμε έξυπνες μεθόδους για την απλούστευση και τη βελτίωση των καθημερινών δραστηριοτήτων που αφορούν το οικιακό αυτό χώρο. Ωστόσο, ενώ αναμένεται ότι κάθε σπίτι θα πρέπει να παρέχει άνεση και ασφάλεια στους κατοίκους του, τα άτομα με αναπηρία αντιμετωπίζουν συχνά προκλήσεις με τα ντουλάπια της κουζίνας τους, καθώς οι χώροι αυτοί δεν ανταποκρίνονται στις καθημερινές τους απαιτήσεις, ενώ προβλήματα όρασης, κινητικοί και γνωσιακοί περιορισμοί, δημιουργούν σημαντικές δυσκολίες ακόμη και όταν επιχειρούνται φαινομενικά "απλές" εργασίες. Για την αντιμετώπιση αυτού του προβλήματος, η παρούσα εργασία προτείνει ένα «Έξυπνο και Προσβάσιμο Έπιπλο Αποθήκευσης» για την Κουζίνα που έχει σχεδιαστεί για να βελτιώνει τη διαχείριση των αποθεμάτων και να βοηθάει στη διαδικασία μαγειρέματος.

Το «Έξυπνο και Προσβάσιμο Έπιπλο Αποθήκευσης» είναι ένα πρωτότυπο σύστημα αποθήκευσης για την κουζίνα, το οποίο σχεδιάστηκε ακολουθώντας τις «Αρχές Σχεδίασης για Όλους» και της «Συμπερίληψης» και απευθύνεται σε ένα ευρύ φάσμα χρηστών, όπως ενήλικες, παιδιά, ηλικιωμένους και άτομα με αναπηρίες. Σχεδιασμένο με γνώμονα την προσβασιμότητα, ενσωματώνει προηγμένες τεχνολογίες και πλήθος αισθητήρων για τη συλλογή λεπτομερών

πληροφοριών σχετικά με κάθε αποθηκευμένο τρόφιμο, συμπεριλαμβανομένου του τύπου, της ακριβούς θέσης, της ποσότητας και της ημερομηνίας λήξης. Το ντουλάπι διευκολύνει την πολυτροπική επικοινωνία χρησιμοποιώντας μια πληθώρα καναλιών εισόδου και εξόδου μέσω των οποίων οι χρήστες έχουν την ευελιξία να αλληλεπιδρούν με το ντουλάπι χρησιμοποιώντας είτε φωνητικές εντολές ή μια φιλική προς το χρήστη διεπαφή οθόνης αφής. Όσον αφορά την έξοδο, το ντουλάπι χρησιμοποιεί φωτισμό LED για την παροχή πληροφοριών με χρωματική κωδικοποίηση, παρέχει ακουστικές απαντήσεις και χρησιμοποιεί διάφορους τύπους δονήσεων για να μεταφέρει σχετική ανατροφοδότηση στους χρήστες.

Το «Έξυπνο και Προσβάσιμο Έπιπλο Αποθήκευσης» κουζίνας προσφέρει μια σειρά από θεμελιώδεις λειτουργίες που αποσκοπούν στη βελτίωση της εμπειρίας του χρήστη. Αυτές περιλαμβάνουν: (α) Την υποβοήθηση των χρηστών στη διαχείριση και οργάνωση των ειδών διατροφής εντός των διαθέσιμων θέσεων, απλοποιώντας τη διαδικασία αποθήκευσης. (β) Την ενσωμάτωσή του με το σύστημα "AmI Chef" παρέχοντας πολύτιμη υποστήριξη και βοήθεια καθ' όλη τη διάρκεια της διαδικασίας μαγειρέματος. (γ) Την παροχή στους χρήστες ολοκληρωμένων πληροφοριών σχετικά με την κατάσταση και τα στοιχεία κάθε αποθηκευμένου προϊόντος, συμπεριλαμβανομένων των επιπέδων ποσότητας και των ημερομηνιών λήξης. (δ) την άμεση ειδοποίηση των χρηστών όταν τα αποθέματα της κουζίνας απαιτούν αναπλήρωση, εξασφαλίζοντας ένα καλά εφοδιασμένο ντουλάπι. Κυρίως, ο σχεδιασμός του δίνει προτεραιότητα στην προσβασιμότητα, επιτρέποντας σε άτομα με διαφορετικές φυσικές ή γνωσιακές ικανότητες να συμμετέχουν εύκολα και να απολαμβάνουν όλες τις προαναφερθείσες λειτουργίες.

Η παρούσα εργασία περιλαμβάνει: (α) Την καταγραφή των προκλήσεων και δυσκολιών που αντιμετωπίζουν οι χρήστες (τόσο με όσο και χωρίς αναπηρίες) όταν αξιολογούν την κατάσταση των αποθεμάτων τροφίμων τους. (β) Μια ολοκληρωμένη ανάλυση των υφιστάμενων έξυπνων ντουλαπιών κουζίνας και συστημάτων αποθήκευσης, με ιδιαίτερη έμφαση στα περιορισμένα χαρακτηριστικά προσβασιμότητάς τους και στις αδυναμίες τους να ανταποκριθούν στις ανάγκες των χρηστών με διαφορετικές ικανότητες. (γ) Μια εκτενή περιγραφή του σχεδιασμού και των λειτουργικών απαιτήσεων του «Έξυπνου και Προσβάσιμου Επίπλου Αποθήκευσης», συμπεριλαμβανομένης μιας λεπτομερούς επισκόπησης των στοιχείων που απαρτίζουν το ντουλάπι και των διασυνδέσεών του, στοχεύοντας στην παροχή μιας απρόσκοπτης εμπειρίας χρήστη και στην προσαρμογή του στις ειδικές απαιτήσεις διαφορετικών ομάδων χρηστών. Τέλος, αναφέρονται τα ευρήματα και τις πολύτιμες γνώσεις που προέκυψαν από μια σειρά μελετών αξιολόγησης (Cognitive Walkthrough) που διεξήχθησαν με εμπειρογνώμονες στην Αλληλεπίδραση Ανθρώπου-Υπολογιστή (HCI), συμβάλλοντας με πολύτιμες γνώσεις και προοπτικές στο τελικό αποτέλεσμα και ενισχύοντας τη συνολική εγκυρότητα και σημασία της εργασίας.

Λέξεις κλειδιά: Έξυπνο ντουλάπι, Διάχυτη Νοημοσύνη, Έξυπνη κουζίνα, Προσβασιμότητα, Πολυτροπικότητα.

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Chapter 1

Introduction

1.1 Problem Statement

In a household, the kitchen holds immense significance among all rooms and is often considered the central hub, as it not only serves as a space for meal preparation and consumption, but also acts as a gathering spot for families and friends. It is where people come together to cook delightful meals, engage in conversations around the kitchen table, and carry out everyday activities. With the substantial amount of time spent in the kitchen, there arises a desire to discover intelligent methods to simplify and enhance daily routines. However, while it is expected that every home should provide comfort and safety for its residents, individuals with disabilities often encounter challenges with their kitchen cupboards, as these spaces fail to meet their everyday requirements. Various impairments, such as visual, motor and cognitive, pose significant difficulties even when attempting seemingly "simple" tasks in the kitchen. To address this issue, we present our solution: the "Accessible Smart Kitchen Cupboard," an accessible innovation designed to streamline inventory management and aid in the cooking process.

Cooking in the kitchen can be an enjoyable experience, but it can also present some challenges. One common issue is forgetting where ingredients are located, which can lead not only to frustration and also to wasted time searching for them causing delays in starting or completing a cooking recipe.

This is especially problematic if you have time constraints or if you're cooking for guests or a special occasion. To avoid this problem, it is essential to keep ingredients organized and stored in designated locations. Additionally, people need to be informed of the current status of the inventory, so they know when to restock essential items like spices, cans, and other food staples. Without this knowledge, it can be challenging to plan meals and maintain a well-stocked kitchen. Another problem is the need for assistance in inventory organization. This challenge is faced not only by individuals with mobility or cognitive impairments but also by those without disabilities who often struggle due to time constraints. In today's fast-paced world, people often find themselves lacking the time needed to effectively manage their inventory. Moreover, it is worth noting that people often opt for a "first fit" technique when storing items instead of utilizing the more efficient "best fit" approach, which sharpens the need for inventory management assistance and for a system to assist them keeping track of their supplies. Overall, addressing these issues can improve the cooking experience and make the kitchen a more enjoyable and efficient space for all.

1.2 Motivation

The driving force behind the development of a smart kitchen cupboard prototype, is the accessibility challenges that people with motion, visual and hearing impairments as well as the elderly, face when using a common one. The design and implementation of this prototype address the problem in a way that the special needs of these people are met while at the same time a more accessible and user-friendly solution is provided. The latter setting could help them perform daily tasks in the kitchen with greater ease and efficiency. The significant impact of prioritizing the needs of these vulnerable groups is

revolutionary as this innovative technology enhances their quality of life and empowers them to live more independently.

The above-mentioned user target groups, elderly or people with motion, visual, and hearing impairments often face significant challenges in the kitchen area. High shelves can be a particular problem for individuals with limited mobility, as they may struggle to reach items stored there safely. The danger of falling items is also a concern, especially for those with visual impairments who may have difficulty spotting items that have been precariously placed. Slippery handles and deep, unreachable storage spaces can present additional hazards, making it difficult to access items safely. Furthermore, forgetfulness can be a significant issue for elderly people with lower memory capabilities, making it challenging to remember where ingredients are stored or what is available in their kitchen inventory.

1.3 Proposed approach

The proposed “Accessible Smart Kitchen Cupboard” [1], which is the focus of this thesis work, utilizes AI technology to recognize the items stored inside it. Additionally, it employs LED stripes to provide notifications and indicate the positions of ingredients. This feature is particularly helpful for elderly individuals as it reduces the time spent searching for items. Notifications can be customized to alert users about low quantities of ingredients or expiring products that could potentially cause serious health problems such as foodborne illness or infections.

Furthermore, the prototype supports multimodality for various different usage cases. Specifically, the kitchen cupboard can be opened and closed using various touch types and can interact with different voice commands. The well-

designed touchscreen display provides vital information about the status of the stored ingredients.

1.4 Thesis structure

The rest of this thesis is divided in 7 chapters as indicated in the table of contents. Chapter 2 dives into the Background Theory and Related Work, offering a solid foundation for the subsequent chapters and presenting the most relevant state-of-the-art systems in the concept of smart cabinets. In Chapter 3, the Concept Definition is thoroughly examined, outlining the key components and features of our Accessible Smart Kitchen Cupboard prototype. Chapter 4 focuses on Requirement Elicitation & Analysis, exploring the necessary criteria and specifications for the project. The development of the Accessible Smart Kitchen Cupboard Prototype is documented in Chapter 5, presenting the innovative solution in detail. In Chapter 6, the evaluation of the Cupboard's Prototype is conducted, assessing its performance and functionality. Finally, Chapter 7 summarizes the findings and suggests potential directions for further exploration.

Chapter 2

Background Theory and Related Work

The current chapter presents the background theory, which focuses on the accessibility challenges of implementing a smart accessible kitchen cupboard. In addition, it provides a review of the most relevant and related systems in the literature, highlighting their strengths and weaknesses and coming with ideas that could be applied to the design of our own prototype. Finally, it presents a detailed discussion and comparison of the existing systems with the proposed own Accessible Smart Kitchen Cupboard prototype, highlighting its innovation and its ability to address people with different types of disabilities.

2.1 Background theory

Designing and implementing an accessible smart kitchen cupboard prototype involves not only engineering challenges but also some accessibility challenges that must be addressed. The cupboard needs to be accessible to people with different types of impairments, such as visual, hearing, and motion impairments, as well as elderly individuals as they frequently face various issues in their kitchen domestic area.

2.1.1 Accessibility difficulties in kitchen area

Challenges for people with visual impairments

People with visual impairments face many obstacles when they cook posed by their visual limitations. First of all, they have difficulties recognizing various groceries and ingredients, which can lead to confusion and mistakes while preparing a meal [2]. They may also forget where items are located in the kitchen, leading to extra time spent searching and allocating food. This can make the cooking process frustrating and time-consuming [3].

Last but most importantly, visually impaired individuals may encounter potentially dangerous situations in the kitchen while cooking. For example, they might face difficulty in safely reaching objects stored on high shelves. Attempting to reach for them without assistance can result in falls or the accidental knocking over of other items, potentially causing injuries or damage. They may also bump into the doors of upper cabinets, sharp edges, or protruding handles, which can cause cuts and bruises [4].

Overall, cooking for visually impaired people can be a time-consuming and stressful experience, as they need to ensure that the procedure has been completed correctly and safely. This can enhance feelings of dependency and isolation, as they may end up asking for assistance from other individuals. However, by leveraging alternative modalities, such as voice commands, visually impaired individuals can experience a significant improvement in their cooking experience. Voice commands enable them to interact with kitchen appliances, tools, and digital assistants, providing them with a more accessible and independent means of carrying out tasks in the kitchen.

Challenges for people with mobility impairments

People with motion impairments and especially wheelchair individuals have to overcome various challenges while cooking, such as accessing high or deep cabinets and needing to bend down to touch lower storage, which can be difficult and cause discomfort [5].

Storage cabinets can limit visibility of the contents, making it difficult to locate the items they need. This can lead to frustration and prolong the cooking process [6]. Additionally, there is an increased risk of heavy items falling, especially when searching for items in high storage cabinets. One way to mitigate the risk of heavy items falling from high storage cabinets is to install pull-out drawers or shelves, which provide easy access to items without having to reach or stretch for them [7].

Moreover, users of wheelchairs require additional space compared to those who stand, and therefore need to exercise caution when navigating in the kitchen. It is important to note that turning requires a considerable amount of room, which can be particularly challenging for users who need both hands to control their wheelchair's wheels. They must be mindful not to collide with any other objects in the kitchen to avoid damaging their wheelchair or injuring themselves [8].

An accessible solution for people with motion disabilities would be a smart kitchen storage system that would offer a lowered height that eliminates the challenges associated with reaching high cabinets. Moreover, this smart storage space would incorporate automated opening and closing mechanisms, minimizing the physical effort required to access and retrieve items and will not be considered as one more obstacle in the kitchen area. By combining these features, this accessible kitchen storage solution would empower

individuals with motion disabilities to navigate their kitchen with ease and independence, without compromising on space efficiency.

Challenges for the elderly

As people grow older, their ability to perform everyday tasks such as cooking can decline. The kitchen, in particular, can present a range of challenges for seniors. Inadequate lighting inside kitchen cupboards can make it difficult to find items, leading to frustration and safety concerns [9]. Moreover, bending and kneeling problems can make it hard to access items on deep or short shelves, causing discomfort and making it difficult to prepare meals independently [10]. Furthermore, seniors with limited mobility may experience difficulties reaching kitchen cabinets, leading to feelings of helplessness and discouragement [11]. To ensure that seniors can maintain their independence and lead fulfilling lives in their homes, it's essential to design kitchen storage spaces that meet their unique needs.

Challenges for people with hearing impairments

Deaf people and individuals with hearing impairments need to cope with several challenges when it comes to using smart devices that receive voice commands because these devices provide mainly sound notifications as their output modality. This can result in missed alerts and dangerous situations. To address this issue, one effective solution-approach method is the use of color-coded abstract highlighting notifications by LED integrated into the user environment. This approach provides a visual cue that can be easily recognized and understood by individuals with hearing impairments [12]. In addition to this, alternative sensing techniques have been developed that make use of vibration sensing. Vibration sensing contains interpretable elements such as vibration size, frequency, and modes [13]. By incorporating vibration

sensing into smart devices, individuals with hearing impairments can receive critical alerts and notifications without relying on sound, ensuring that they do not miss any important information.

2.2 Related Work Overview

The current section presents the scientific attempts most closely related to the concept of smart storage cabinets from 2009 to 2022. The state-of-the-art approaches presented below utilize IoT technology and recommend solutions that can be applied in everyday casual homes. The related work overview revealed that smart kitchen cupboards can serve many purposes and address various issues.

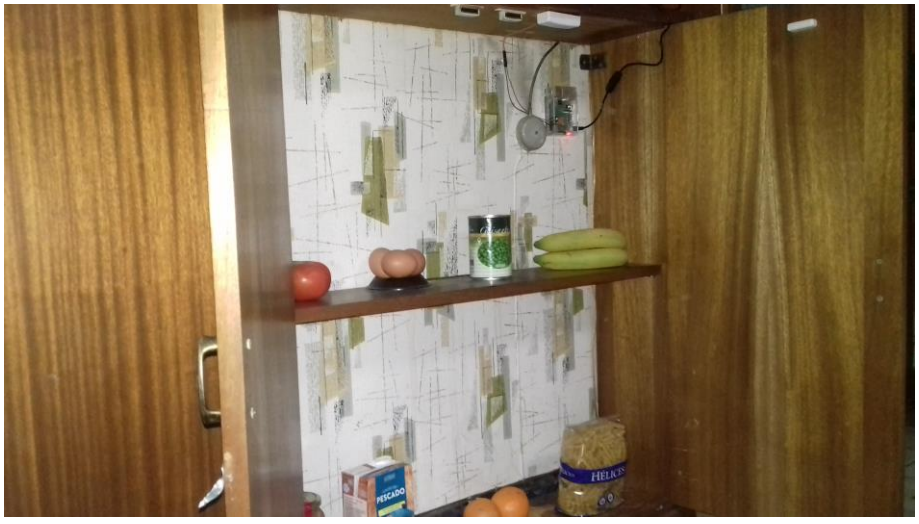

Figure 1 : "A prototype of a collaborative IoT smart cupboard for assessing memory losses" [14]

"**Collaborative IoT Smart Cupboards**" [14] explores the concept of collaboration between Internet of Things (IoT) devices in creating a smarter environment. The authors developed a collaborative smart home system to track memory loss using smart cupboards. Their goal was to detect symptoms

of memory loss, such as dementia and Alzheimer's disease, by observing patterns in how individuals searched for ingredients. To achieve this, they equipped the kitchen cupboards with door sensors that monitored their status (open or closed), and used a Raspberry Pi 3 to process the signals and communicate with a laptop via Wi-Fi. The result was a user-friendly system that could help identify instances of memory loss and support those affected (Fig. 1).

Figure 2 : Three smart cupboards for measuring user's memory [15]

The "**Smart Assessing Memory Cupboard**" [15] presents a novel use of IoT sensor systems in the form of a three-door smart cupboard (Fig. 2) that measures a user's memory to detect potential memory loss. The smart cupboard uses magnetic door sensors connected to a Raspberry Pi to classify events as successful or unsuccessful attempts to find an object. The smart cupboard was tested on 23 users in a controlled environment and the results showed a significant correlation between the accuracy of the smart cupboard test and a validated memory test and a self-reported memory test.

The " **Smart Kitchen Cabinet**"[16] focuses on integrating intelligence into an existing kitchen cabinet for inventory management of grocery items. The system uses RFID tags to identify the items, load sensors (Fig. 3) to measure their weight, and an Intel Atom processor to process the data and update a database. The user can interact with the system through a graphical user interface. The results of the study suggest that the smart kitchen cabinet improves efficiency and convenience in the kitchen by keeping track of grocery items and automatically preparing shopping lists. The authors also suggest that the smartness of the cabinet could be further extended by adding more functionality, such as nutrition-aware cooking and personalized cooking, and exploring image processing techniques to identify the grocery items.

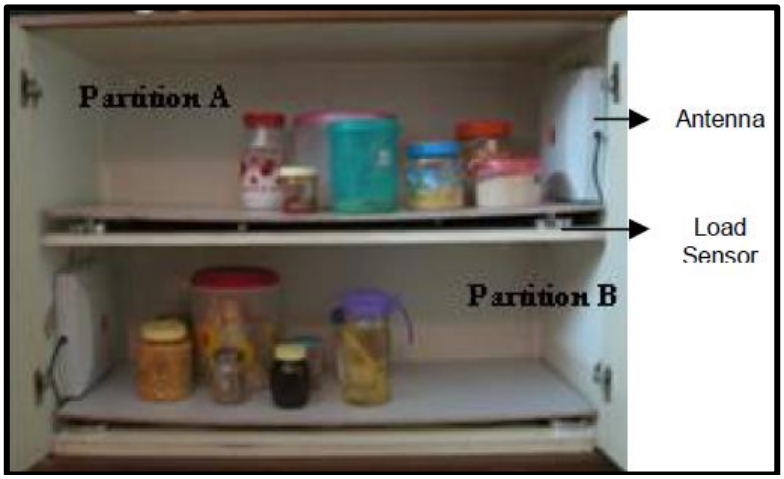

Figure 3 : Smart kitchen Cabinet [16]*, System equipped with RFID readers and load sensors.*

"**Smart pantry**" [17] is an application that aims to help consumers keep track of their pantry inventory and automate item retrieval. The system uses weight sensors to measure the weight of storage containers and calculate the quantity of ingredients in the pantry. The data can be accessed through a mobile

application that generates alerts for replenishment and provides recipes based on the available ingredients. The design takes into account kitchen safety and aims to provide a low-cost, user-friendly solution for real-time pantry monitoring and control. However, there are challenges in the implementation, such as recognizing different barcode positions, which requires image recognition or alternative methods. The future goal is to develop a feature that can recommend recipes based on the components available in the pantry, using machine learning and artificial intelligence.

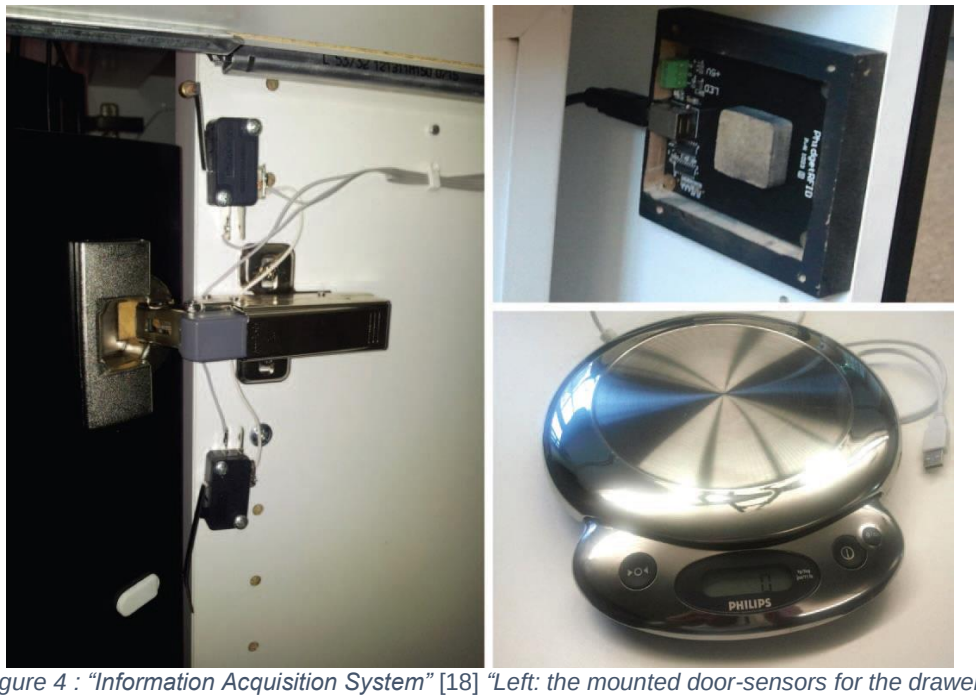

Figure 4 : "Information Acquisition System" [18] *"Left: the mounted door-sensors for the drawer (upper sensor) and door (lower sensor). Upper right: the RFID reader without cover. Lower right: the scale that transmits the weight values"*

"**Information Acquisition System**"[18] is a system that allows monitoring and controlling kitchen appliances remotely. The authors equipped an ordinary kitchen with a variety of state-of-the-art sensors such as inertial sensors, door sensors, and smartphone sensors to enable new forms of interaction. Their goal of their smart kitchen is to support various user interactions, including healthy

living and activity recognition, and user guidance. They decided to monitor cupboard and drawer activities in addition to object recognition. This allows for counting the time the fridge is open, planning a more efficient order of goods in the cupboard, and finding out if the user is searching in the correct place for the correct item in an assisted cooking scenario. Sensors were mounted on the doors and drawers (Fig. 4) and an Arduino Mega 2560 was used for communication between the sensors and computer. A graphical user interface was written to display a live representation of the door states.

A. 

B. 

Figure 5 : Counter Intelligence [19]*: "A. Augmented Reality Kitchen: information projection on the refrigerator (1)*, the range (2), the cabinet (3), the faucet (4) and drawers (5)" B. "Augmented Cabinetry"

"**Counter Intelligence**" [19] is an augmented reality system for kitchens to increase safety, ease, and efficiency of cooking. The system gathers information from the kitchen environment and displays it in a user-friendly manner on various objects and surfaces in the kitchen such as the refrigerator, cabinets, and countertop. The system consists of five context-aware systems, including FridgeCam, RangeFinder, Augmented Cabinetry, HeatSink, and Virtual Recipe (Fig. 5A). Augmented Cabinetry (Fig. 5B), in particular, reduces the time required to locate items in cabinets by illuminating the handles of the cabinets and providing directional cues. The system is controlled by a PIC-based microcontroller through a PC-based Virtual Recipe system and future versions aim to reduce the reliance on a hard-wired network.

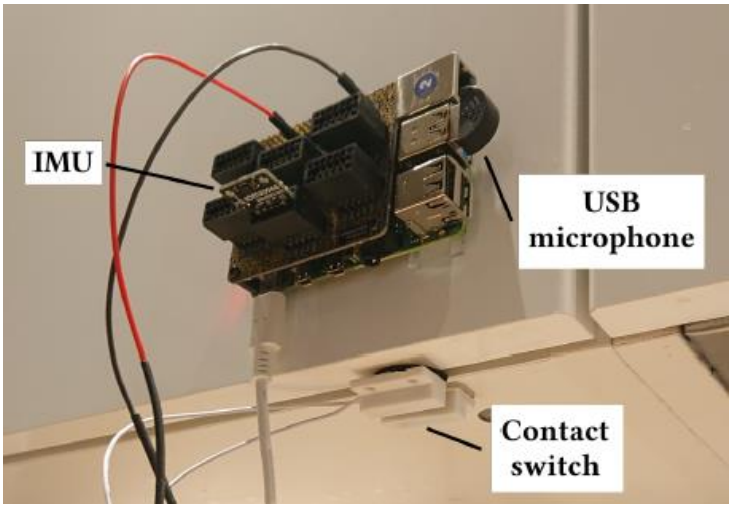

Figure 6 : BeeHIVE [20] *Raspberry Pi attached to a kitchen cupboard. The white magnetic contact switch is used to detect the opening and closing of the cupboard, the USB microphone is used to measure sound pressure levels, and the IMU connected on top of the Raspberry Pi records acceleration, gyroscopic movement and orientation of the interaction.*

"**BeeHIVE**" [20] is a behavioral biometric system which use smart kitchen furniture for user authentication. The system leverages daily interactions

between the user and smart objects to authenticate users without relying on phone-based mechanisms. In addition to traditional smart furniture such as ovens, coffee machines, drawers, and microwaves, the authors demonstrated the potential of a smart cupboard as a biometric authentication device. The cupboard was equipped with contact switches for detecting opening and closing events, a microphone for measuring sound pressure levels, and an IMU (Inertial Measurement Unit) for collecting data on acceleration, gyroscopic movement, and orientation (Fig. 6). This shows the potential for smart objects in the home to be used for biometric authentication in a convenient and seamless manner.

Figure 7 : Smart Drawer [21]*: Left: Smart Drawer system, Right: RFID reader and RFID tags on a bottle*

"**Smart Drawer**"[21] is a system using Radio Frequency Identification (RFID) technology for monitoring medication taking in an assistive environment. Authors' goal is to utilize RFID technology in order to keep track of medicine inventory and monitor the medication taking habits of the elderly (Fig. 7). The system has three main users: the patient, the caregiver, and the maintainer. The patient view has an alert system, a historical data access interface, and a set of instructions. The caregiver view has options for updating prescriptions and accessing historical data. The maintainer is the administrator of the system, with options for modifying functionalities and accessing stored data. The authors have completed a hardware investigation and have developed prototype user interfaces for the system. The project is

ongoing and aims to expand beyond the prototypes to fulfill the needs of the three types of users.

"**UHF RFID Cabinet**" [22] scientific attempt presents a UHF reader antenna system for tracking pharmaceutical items inside a cabinet using RFID technology (Fig. 8). The system consists of four circularly polarized patch antennas operating at 860 MHz to 868 MHz and has been tested with self-standing tags and tags attached to medical objects, resulting in a good detection rate within the cabinet. The antennas are designed to prevent detection of items outside the cabinet, ensuring proper confinement of electromagnetic fields. The system has been tested with pharmaceutical objects with very satisfactory results, though some compatibility issues with certain materials still need to be addressed.

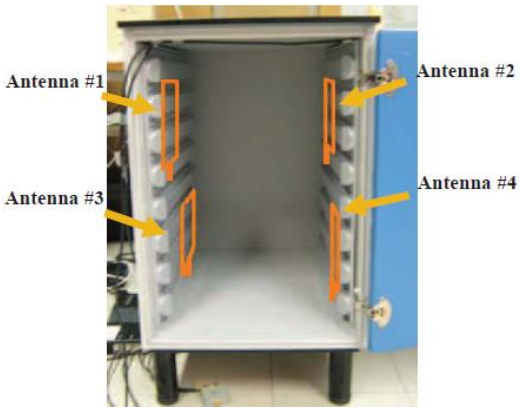

Figure 8 : UHF RFID smart cabinet with four inside reader antennas [22]

2.3 Discussion

The literature review presented on smart kitchen cabinets, or more generally, smart storage systems, has revealed some fascinating approaches and ideas for useful systems. Besides that, it brought to the surface some crucial challenges that an accessible smart kitchen cupboard should overcome.

2.3.1 C1: Tracking kitchen inventory status

Cooking can be quite challenging, especially when it comes to keeping track of your kitchen inventory. Our inventory typically consists of a vast array of food items, ingredients, and supplies, all with varying quantities and expiration dates. It's easy to lose track of what you have and what you need, and sometimes items can become lost or pushed to the back of the cupboard. This can cause wasted time searching for them and turn your fun and creative cooking experience into a stressful one [23]. Instead, a cook needs to know how much of each available ingredient is left and which food products are about to expire, in order to arrange their cooking steps accordingly [24].

2.3.2 C2: Organizing sufficiently kitchen inventory

Keeping the kitchen organized can be a challenge, especially when it comes to managing the inventory of newly purchased food items. After a trip to the supermarket, it can be tempting to simply put everything in the pantry or fridge without much thought, but this can lead to disorganization and potentially wasted food. One strategy for effective kitchen inventory organization is to group similar items together and store them in designated areas. For example, canned goods can be placed in one cupboard while dry goods like pasta and rice can be stored in another storage place. Generally, a well-organized kitchen inventory could save not only time but also money while the food waste is minimized.

2.3.3 C3: Knowing ingredient’s storage location

One of the challenges that we often face while cooking is knowing the location of each ingredient in our kitchen. It can be hard to remember when have been stored the food items that are urgently needed especially in cases that either the inventory has many different food items or there is no proper grouping in kitchen cabinets. The problem of forgetting the storage location of food supplies is vital for elderly people with low quality memory or people with cognitive impairments. Therefore, it is important to create a kitchen environment that not only facilitates easy storage and organization of food items but also provides quick access to information about their location upon request.

2.3.4 C4: Locating desired food items

One more challenge that many people face in a kitchen area is locating a specific food item in kitchen cupboards. Inadequate lighting in storage places can cause limited visibility which makes it difficult to differentiate between similar looking food items [6]. Considering people with a potential visual impairment or elderly people with low quality vision can be easily understood that someone could end up searching for a long time without success. To address this issue, it is essential to have proper lighting in kitchen storage areas which can be achievied by installing LED lights inside the kitchen cupboards. These lights can significantly improve visibility and make it easier to locate food supplies.

2.3.5 C5: Inaccessible deep and high storage spaces

One of the major challenges in kitchen design is the problem of inaccessible deep and high storage spaces [5]. These storage areas can be difficult to access

for people of all ages and abilities, but they can be particularly challenging for seniors or people with mobility issues. Trying to reach items on high shelves can be dangerous, and accessing items in deep cabinets can be uncomfortable or even painful. This can make it difficult for people to prepare meals or access necessary kitchen items, which can impact their independence and quality of life. Designing storage spaces that are accessible and easy to use for people of all abilities is an important consideration in creating a safe and functional kitchen.

2.3.6 C6: Need for user-friendly interactions

Developing smart storage systems presents a significant challenge in terms of complexity. Although these systems aim to be intelligent and efficient, their complexity can sometimes make them difficult for users to manage. Therefore, simplifying smart storage systems and making them more user-friendly is crucial to address this challenge. By adopting an intuitive and straightforward interface that facilitates easy and casual interaction, these systems can become more accessible and approachable to users [25]. Prioritizing the needs of users can lead to a smoother and more enjoyable experience with smart storage systems.

2.3.7 Comparison

The idea of augmenting smart storage places with ambient intelligence (AmI) in the kitchen domestic area in order to improve users' daily habits is not new. However, there is not a complete accessible smart kitchen cupboard [1] that

supports cooking assistance, food storage management and provides information about food supplies in a kitchen pantry.

The above-mentioned challenges have been addressed by various existing literature reviewed systems related to the topic of smart kitchen storage systems. These systems faced the respective challenge in a less satisfactory way or it was fully framed. This can be seen in table 1 where the more color-filled the circle for each challenge, the more adequately the corresponding challenge was approached and solved.

As it can be seen from table 1, almost none of the reviewed systems considered the crucial factor of accessibility (C5), except from [19],[20] and [21] that are designed for including elderly as well. This omission is significant as it limits the potential user base and excludes elderly individuals or people with impairments such as visual, motor, or hearing disabilities from using the system.

Moreover, the challenge of locating items inside a storage place (C4) by providing directional cues, such as colored lights or alternative sensing, is clearly a scientific area that needs further study. The only scientific approach that adequately addressed the challenge of locating items was [19], where the technology-augmented cabinet was equipped with an illuminated handle and provided proper indications to the user.

In contrast with all the other related systems, our designed prototype, the Accessible Smart Kitchen Cupboard [1] aims to address all the aforementioned challenges with state-of-the-art solutions using cutting-edge technologies and it aims to be usable by users with disabilities as well.

● : Shows the completion level of each challenge by each system

		C1	C2	C3	C4	C5	C6
Literature Review Systems	**"Collaborative IoT Smart Cupboards"** [14]	○	◔	○	○	○	◕
	"Smart Assessing Memory Cupboard"[15]	○	◔	○	○	○	◕
	"Smart Kitchen Cabinet" [16]	●	◑	●	◔	◔	◕
	"Smart pantry" [17]	◕	○	○	○	○	○
	"Information Acquisition System" [18]	○	○		○	○	◕
	"Counter Intelligence" [19]	○	○	◕	◕	◕	●
	"BeeHIVE" [20]	○	○	○	○	◕	◕
	"Smart Drawer" [21]	◑	○	◕	○	◑	●
	"UHF RFID Cabinet" [22]	◔	○	◕	◔	○	○
	Accessible Smart Kitchen Cupboard [1]	●	●	●	●	●	◕

Table 1 : Comparison between existing smart storage systems and Accessible Smart Kitchen Cupboard

Chapter 3

Concept Definition

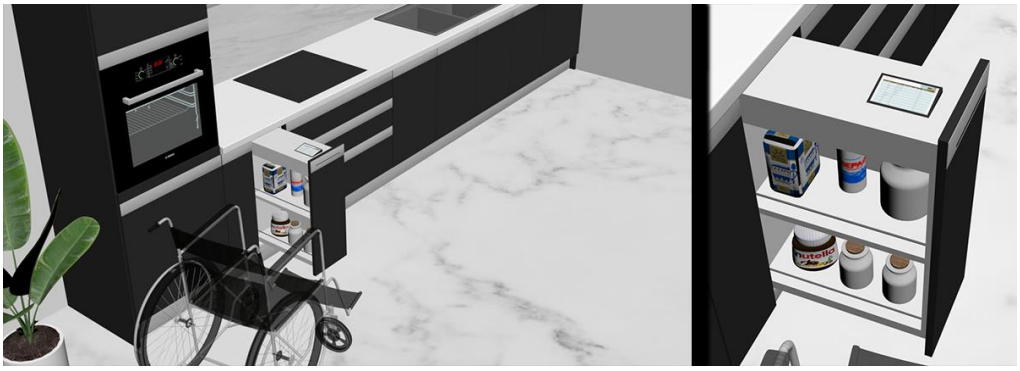

Figure 9 : 3D representation of the accessible smart kitchen cupboard placed in a typical kitchen.

A modern kitchen should be a functional space that enables people to efficiently carry out their daily tasks. A well-designed kitchen and storage system should facilitate meal preparation and organization, as well as provide a pleasant environment in which to work. The vision of a kitchen with an effective storage system would feature sufficient storage space with easily accessible cabinets and drawers, maximizing the use of space and minimizing clutter. Overall, the goal of an efficient kitchen and storage system is to make everyday tasks like cooking and storing as “automated” and stress-free as possible [26].

3.1 Target user groups

The proposed Accessible Smart Kitchen Cupboard is an innovative solution that is going to change the way people interact with their kitchen cabinets. This smart technology is designed to cater to the needs of everyone, including people with impairments. The appeal of this innovative prototype lies in its ability to be accessible to all, making it an inclusive solution. The cupboard offers a user-friendly interface and a range of input/output options, allowing people of all physical abilities to interact with it effortlessly and smoothly. This smart kitchen cupboard is an exciting development that is set to change the way we store and access our kitchen items.

3.2 Cupboard furniture

The current thesis work is a significant step towards achieving the goal of creating an inclusive and accessible living environment for people of all abilities [27]. The Accessible Smart Kitchen Cupboard prototype (Fig. 10) is a innovation that can be integrated into an intelligent kitchen [28]. This wooden cupboard is 45cm x 58cm x 85cm (W x D x H) in size, making it suitable for food storage, and it can be conveniently placed under the kitchen countertop.

The design of the furniture is geared towards meeting the unique needs of individuals with different abilities, including blind individuals, wheelchair users, people with mild cognitive impairments, the elderly, and people without disabilities. The Accessible Smart Kitchen Cupboard has been designed to be inclusive and accessible to all.

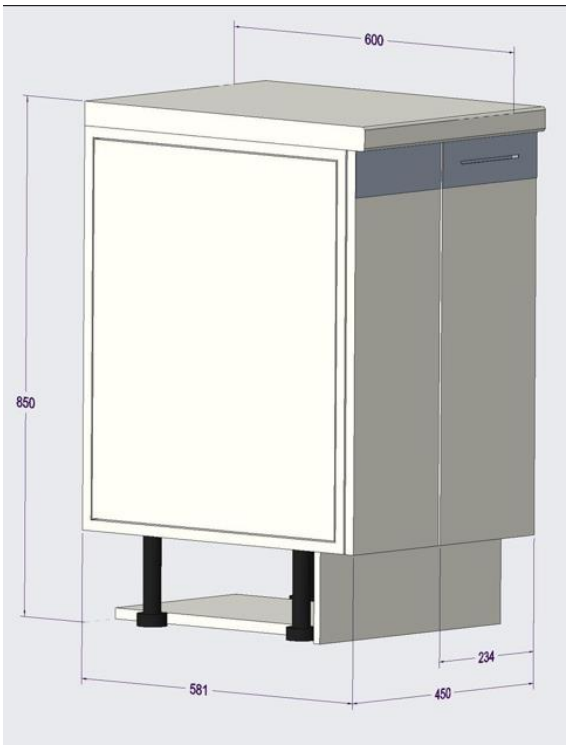

Figure 10 : Dimensions of the Accessible Smart Kitchen Cupboard prototype

The Accessible Smart Kitchen Cupboard differs from traditional wall cabinets that are typically installed above the kitchen countertop. The smart cupboard's design is suited for wheelchair users who experience difficulty reaching high items. It is placed under the kitchen countertop, and the height of the countertop satisfies the universal range of 760-860mm. [29]. This feature makes it a practical and accessible storage solution for people with mobility impairments. Additionally, the cupboard opens by pulling out (see Fig. 13), which addresses the common challenge of not being able to reach deep storage places, particularly for older adults [10].

3.2.1 Interaction modalities

The Accessible Smart Kitchen Cupboard prototype boasts a range of innovative and inclusive features, including multimodal I/O, designed to cater to the interaction preferences of its diverse user base. The user can control the moving part of the cupboard through a **touch-sensitive metallic plate** located on the upper part of its front face, allowing for ease of use and accessibility. The touch screen, appropriately tilted and placed on the upper shelf, enables users to view essential details about the stored products, such as their expiration date, quantity, location, and statistical information about their use. Users can also select items to be retrieved, and multiple **colored LED strips** illuminate to indicate the status and location of the requested products (Fig. 11). For instance, the yellow color indicates imminent expiration, and a specific item illuminates to guide users with cognitive impairments.

Figure 11 : The LED stripe of the upper shelf of the smart cupboard lighted up green

The smart cupboard also integrates with a **voice assistant**, making it a convenient and accessible storage solution for users whose hands are unavailable, such as when they are dirty during cooking. The user can use

voice commands to control the cupboard, such as opening or closing the door and locating an item. In addition, **auditory** display and vibrotactile feedback are used to communicate subtle messages to the users, enhancing their overall experience. For example, a chime plays when the cupboard door is opening, promoting safety and avoiding accidents, and the cupboard **vibrates** when the user's hand approaches the correct product.

3.3 Cupboard intelligent components

3.3.1 The cupboard left-hinged door

One of the most innovative and valuable features of the Accessible Smart Kitchen Cupboard prototype is its "Scanning Procedure," which allows the cupboard to collect and process information for every product contained inside it through machine learning [30]. To accomplish this, **a small camera** is installed in the left fixed part of the cupboard (Fig. 12), secured by two metallic rails, and moves across a perpendicular plane to view and recognize the contained food items. This innovative design ensures that the camera can scan each item in the cupboard to gather precise information about it, without disturbing the user during cooking or other activities. The scanning process is set to run during "off" hours, with a "quick" scan during busy cooking hours and a "deep" scan late at night while the user is sleeping.

Through this process, the Accessible Smart Kitchen Cupboard can identify and track important information for each item, including its kind, quantity, and expected expiration time (based on its kind), approximate location on a shelf, the time it was initially inserted, and the time of its first and last use. This

detailed information is then shared with the Intelligent Kitchen, turning the smart cupboard into an intelligent assistant that can support users while cooking.

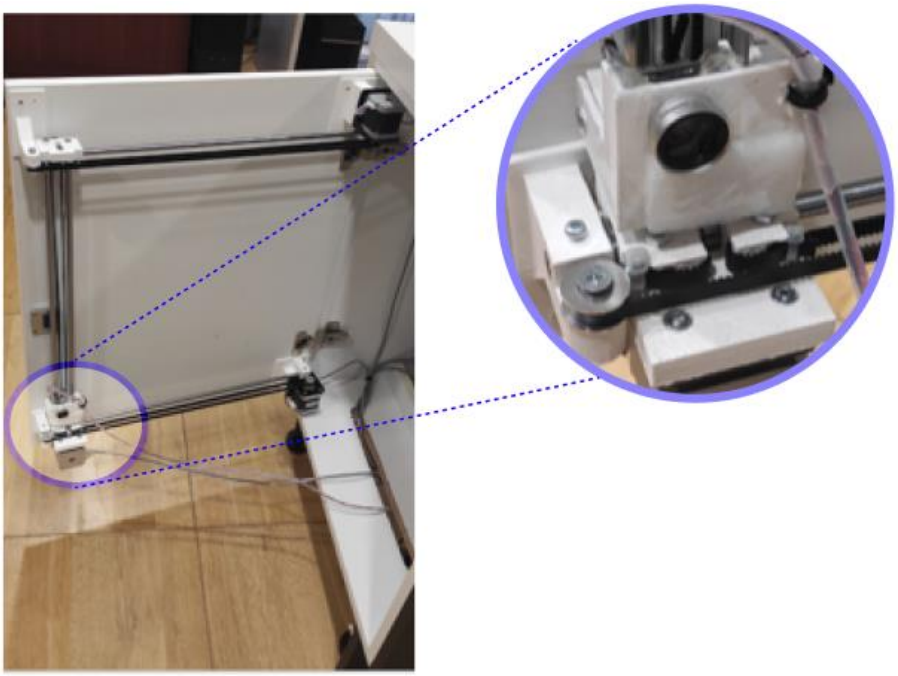

Figure 12 : Cupboard camera for image recognition purposes

The Intelligent Kitchen [28] uses this information to help users manage their supplies and ingredients more efficiently. For example, it can remind users where a specific item is located, suggest recipes based on the ingredients available, and inform them when it's time to replenish their supplies. This is especially useful for items that are about to expire, allowing users to consume them before they go bad or restock them in time.

3.3.2 The cupboard door

The furniture on the right side of the Accessible Smart Kitchen Cupboard prototype is a **motorized sliding column** known as the cupboard door (Fig. 13). This remarkable feature is designed to provide an efficient and accessible storage solution for everyday food items. It comprises two shelves that extend mechanically along its horizontal axis, offering ample space for storage. To prevent items from falling down, a metallic horizontal bar is placed in front of the shelves, ensuring the safety and security of the stored items.

Figure 13 : Cupboard door. The two-ways red arrows signify the door's movement.

Furthermore, the top part of the cupboard is fitted with a colored LED strip, which enhances the user's experience by indicating a variety of situations to the user. For example, the green color shows that the desired food ingredient is

available in the specific cupboard. The red color is a notification to the user about expiring or close-to-expiring foods, promoting food safety and reducing waste. The yellow color indicates the number of available empty slots for storage, which is an excellent feature for individuals who like to plan their meals and keep their kitchen organized.

3.3.3 The cupboard scales

The cupboard shelves are equipped with highly accurate weight scales that allow for precise measurement of the quantity level of placed food items (Fig. 14). The weight scales are 3D printed using durable plastic material and are expertly nailed to the shelf to create clear and distinct storage slots. This innovative design allows the system to determine whether a slot is empty or not, enabling efficient and organized storage of food items.

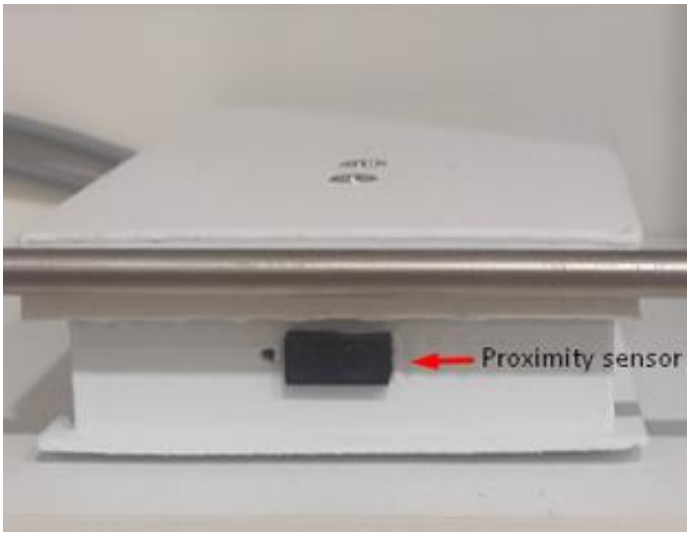

Figure 14 : Cupboard scale with its embedded proximity sensor

In addition to their accurate measurement capabilities, the cupboard scales also contribute to some very useful features of the cupboard in general. For

instance, if a user picks up an item from the shelf, an auxiliary auditory signal notifies them about the kind and quantity of the picked item. This feature is particularly helpful for busy individuals who need to quickly identify items while cooking or preparing meals.

Moreover, the scales embed a proximity sensor that can detect when a hand is moving towards them. If there is a food item on a scale while the human hand scans along, the scale will generate a subtle vibration to indicate its presence and location. These last two features could be extremely helpful and improve the cooking experience, especially for people with serious visual impairments who cannot rely on their vision. By providing tactile feedback and precise location information, these individuals can confidently and independently navigate their kitchen cupboards inventory, enhancing their ability to prepare meals with ease and efficiency.

Chapter 4

Requirement Elicitation & Analysis

This chapter presents the requirements for the design and the implementation of the Accessible Smart Kitchen Cupboard prototype. Firstly, it describes the user-centered design process that was used, presents the motivating usage scenarios for various different user groups and finally counts the functional requirements of the system.

4.1 Design Process

The Engineering Design Process [31][32] is a structured and systematic approach to problem-solving used in the field of engineering. It is a framework that assists engineers while designing and developing new products or systems that meet the needs of the stakeholders. The specific steps involved in the process may vary depending on the context, but a general outline of the process includes the following steps:

1. Define the problem: Our team carefully analyzed the needs and requirements of individuals with varying physical abilities, ensuring that the smart accessible kitchen cupboard addressed their specific challenges effectively.

2. Research and gather information: Our team conducted thorough research on existing accessible kitchen solutions, consulted with stakeholders, and gained insights from individuals with disabilities to inform the design process of the smart accessible kitchen cupboard.

3. Brainstorm and generate ideas: Our team facilitated brainstorming sessions, incorporating diverse perspectives and utilizing creative techniques to generate innovative ideas for the design of the smart cupboard.

4. Choose the best solution: After a comprehensive evaluation and comparison of different design options, we selected the most suitable solution that met the design requirements, considering factors such as ease of use, safety, and accessibility for individuals with disabilities.

5. Develop a prototype: In this step, we developed a realistic prototype of the smart accessible kitchen cupboard, combining physical and digital elements to create a functional representation of the final solution. This allowed us to assess its usability and gather feedback for further improvements.

6. Test and evaluate the prototype: Detailed testing was conducted on the prototype to ensure that it met the design requirements, including testing for accessibility, accuracy, and user-friendliness. Our team considered a wide range of scenarios and conditions to guarantee optimal performance.

7. Refine the design: Based on the feedback and insights gathered from testing and evaluation, we iteratively refined the design of the smart accessible kitchen cupboard, making necessary adjustments to enhance its functionality, accessibility, and overall user experience.

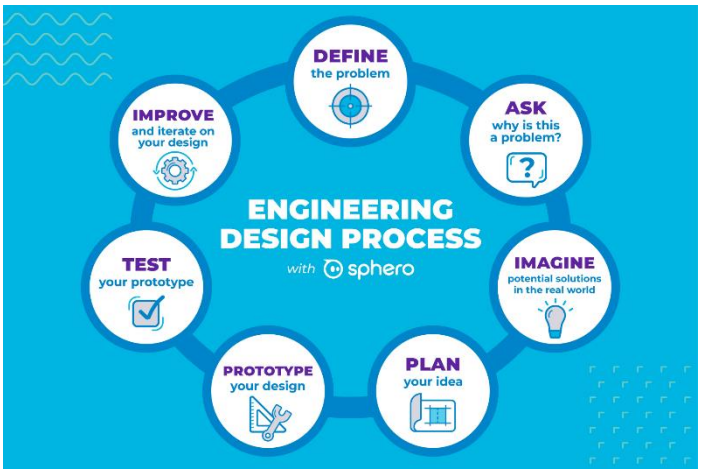

Figure 15 : Engineering design process steps[2]

4.2 Requirements

The current section presents all the high-level functional user requirements that the Accessible Smart Kitchen Cupboard meets. The following requirements collection was based on an in-depth literature review and it was focused on the various accessibility needs of different people groups.

4.2.1 General functionalities

FR-1: The user should be able to view all the available products in the cupboard.

FR-2: The user should be able to check whether a product exists in the cupboard.

[2] https://sphero.com/blogs/news/engineering-design-process

FR-3: The user should be able to open the cupboard door easily (i.e., without the need of applying any force).

FR-4: The user should be able to be informed about the cupboard's door status.

- Totally open
- Semi open
- Closed

FR-5: The user should be able to be informed about the transition from one cupboard door status to another.

FR-6: The user should be able to filter the existing products of every cupboard based on the following criteria:

- Quantity
- Expiring date
- Storage shelf

FR-7: The user should be able to locate the position of any product inside the cupboard.

FR-8: The user should be able to view detailed information about every product:

- Total number of items
- Total quantity in grams
- For each individual item of the product:
    - Name
    - An image of the product's package
    - Cupboard where is placed

- Shelf where is placed
- Quantity in grammars
- Insertion date
- Date first opened
- Date that was last used
- Expiration date
- An indication about the item’s state
    - Low in quantity
    - Close to expiration date

4.2.2 Inventory organization functionalities

FR-9: The user should be able to add either an already known product.

FR-10: The user should be able to inquire about the available storage space inside each cupboard.

FR-11: The user should be able to find a specific product without looking in the cupboard.

FR-12: The user should be able to receive assistance in locating the desired products inside the cupboard.

FR-13: The user should be able to update the smart cupboard about the expiration date of a product when uses it for the first time (two identical product items may have been purchased at different times).

FR-14: The user should be assisted in placing a product in its usual spot.

FR-15: The user should be notified about the amount of available space in a cupboard.

- Which cupboards do have available space.
- How many products can be placed in each cupboard.

FR-16: The user should be able to define which cupboards can be used by which person.

FR-17: The user should be able to learn and specify the purpose (themes) that each cupboard satisfies. Some indicative examples of cupboards themes are the following:

- Kitchen utensils
- Cans
- Legumes

4.2.3 Cupboard's Indications

All users should be able to get and be guided and informed by the various indications that the Accessible Smart Kitchen Cupboard provide. Some of the system supported indications are about finding where a product is stored, providing information about the process of the cupboard's scanning procedure and pointing out the available empty slots inside the cupboards.

FR-18: The user should be able to be know whether the scanning procedure has indeed started.

FR-19: The user should be informed about the progress of the scanning procedure.

-The user should be able to see an estimation of the remaining time of the scanning procedure.

FR-20: The user should be informed that the scanning procedure has been completed.

FR-21: The user should be able to know in which cupboard a particular product is located.

FR-22: The user should be able to be informed about the state of a specific product.

- Close to expiring
- Low quantity
- Neither of the above

FR-23: The user should be informed about the position of one or more products inside the cupboard.

4.2.4 Cooking assistance functionalities

One of main aspect of the Accessible Smart Kitchen Cupboard is assisting in every-day cooking procedure. Smart cabinets are able to inform users about the location of the necessary ingredients of the recipe to be executed and facilitate access to them.

FR-24: The user should be able to set the total kitchen in a recipe mode (devices and furniture are aware for executing a cooking recipe).

FR-25: The user should be able to ask which cupboards contain ingredients associated with the selected recipe.

FR-26: The user should be assisted in accessing the ingredients that are related to the current step of the recipe by being indicated in which cupboard they are stored and their exact position within it.

FR-27: The user should receive information regarding the sufficiency of the ingredients that are stored in the cupboards and are related to the current step of the recipe.

4.3 Motivating scenarios

Motivating scenarios, also known as use cases, are descriptions of how a system or product will be used in a specific context by a particular user or group of users. Our team used them to identify and understand the functional requirements that describe the specific tasks and goals the Accessible Smart Kitchen Cupboard must support. Additionally, motivating scenarios helped us identify any constraints or limitations that needed to be considered during the development of the prototype, such as performance requirements, security considerations, or accessibility requirements.

The following sections present various interaction scenarios based on the different accessibility needs of people groups. The Accessible Smart Kitchen Cupboard is designed based on the principles of Design-For-All [27] taking into considerations various parameters such as age, gender, accessibility needs or health impairments.

4.3.1 Motion impaired user

John who is 35-years-old, has a motion disability that necessitates the use of a wheelchair. He wants to prepare a simple pasta meal with some red tomato sauce and he needs to get the tomato can from the cans themed cupboard. Towards that purpose, he says "*Kitchen, locate for me a tomato can*" and the intelligent kitchen system, which can track John's position in the environment, responds "*Please move a little bit to the left as you are standing on the route of the opening cupboard, helping him to avoid getting hurt or frustrated.*" As John moves his wheelchair aside, the cupboard opens automatically, and the tomato can is illuminated so that it can be easily identified and accessed. He approaches the cupboard, grabs the can, and then remembers that he wanted to check various information about the other items in the cupboard before closing it. The cupboard features an integrated titled touchscreen positioned at a height visible from his wheelchair. He takes a look into the touchscreen and gets informed about the quantity and expiration dates of other products in the cupboard. Satisfied with the information he received, Tom closes the cupboard and starts cooking.

4.3.2 Visually impaired user

Mary is a 45-year-old woman with severe visual impairments. She would like to get the coffee package and the sugar in order to prepare her morning coffee. She gives a voice command on her voice-controlled assistant device, stating that she is looking for these two products. The system replies to her, informing that the products she needs are located in the second cupboard. While she is using her hand to navigate along the kitchen bench, the kitchen assists her by providing proper detailed instructions. For example, it says, 'You are in front of the fifth cupboard. Continue moving to the left along the kitchen bench until

you hear the characteristic tone.' When she is informed that she has reached the correct cupboard, she touches it and it opens automatically. Then, she uses her hand to search for the desired products. As her hand passes over the desired products, she feels a characteristic vibration and hears a short tone. As soon as she collects the two products, she closes the cupboard.

4.3.3 Young child

George is a 7-years-old boy and plays in the kitchen room while his parents are away from home. He approaches the cupboard that contains sharp kitchen utensils and tools such as knives, graters and blenders. While he tries to open the cupboard by touching it, the cupboard does not fulfill his wish as he is not authorized to use that specific cupboard and he has no access. The boy is informed about that as he sees a red indication in the front part of the cupboard and hears the following message by the cupboard's speaker, such as "*George you are not authorized to open that cupboard because there are sharp dangerous items inside*.".

4.3.4 Casual user (Homemaker)

Sophia is a 40 years old mother who loves cooking for her family. As she starts cooking a health bean meal, she sets the kitchen in a recipe mode. Immediately, she is notified about the cupboards that contain the bean package and the tomato sauce. As she washes her dirty hands, she is giving a voice command to her voice-controlled assistant device to open the corresponding cupboards. She approaches the cupboards and the two ingredients are lighted up inside the cupboard, so they are quickly and easily identifiable. She picks the two products and continues cooking, having forgotten to close the

cupboard. After some seconds, the Accessible Smart Kitchen Cupboard closes by itself.

Chapter 5

The Accessible Smart Kitchen Cupboard

The architecture of a system or prototype plays a crucial role in its overall effectiveness. The Accessible Smart Kitchen Cupboard presented is not just a typical storage unit. It integrates cutting-edge technologies and consists of software and hardware components that work cooperatively to provide a seamless experience to users. This chapter analyzes firstly in a higher level the architecture of the prototype and then examines in-depth its various components, how they are connected, and the purpose each one serves.

5.1 Cupboard Core Services

The Cupboard Core Services are a set of backend APIs and more specifically locally Flask servers written in Python that receive the user's action intent as input and process the data accordingly. The main purpose of these services is to provide reliable, seamless, and secure interoperability between the data provided by the user and the microcontrollers responsible for controlling the hardware parts of each smart cupboard and achieving the desired action (e.g., opening cupboard doors, lighting notification LEDs). Additionally, the backend APIs can be used as a proxy to provide a gateway between all smart systems in the ambient intelligent environment of the kitchen area and the

Accessible Smart Kitchen Cupboard, which represents a part of the kitchen inventory.

The Cupboard Core Services are logically divided into two main groups. The first part is the Inventory Backend, which has the objective of exchanging data with the prototype's database, knowing the status of each smart cupboard at all times and assigning the input action to the appropriate corresponding cupboard. The second part is the Cupboard Backend, which is responsible for coordinating the various cupboard hardware parts and providing high-quality handlers for every possible action request.

5.1.1 Inventory Manager API

One of the most significant components for the seamless communication and data exchange between the smart kitchen and all the smart kitchen cupboards is the Inventory Manager API. Inventory API is a Python Flask server [33] which primarily serves GET requests allowing every smart device of the ambient intelligent kitchen environment to access crucial information. This information can range from finding which cupboards host an ingredient that satisfies a specific filter (e.g., expiration date) to getting the exact position of a specific ingredient in the kitchen inventory. Overall, the inventory can bridge the communication need of the smart kitchen with the smart cupboards providing the user with a smoother and convenient experience while cooking.

5.1.2 Cupboards Manager API

The Cupboards Manager API is a vital component of the Inventory backend in the smart kitchen cupboards project, enabling efficient management of various actions across different cupboards. As a Python Flask server [33], it provides endpoints that allow for the control of actions such as highlighting cupboard

doors, empty slots positions, and initiating scanning procedures. Additionally, the API plays a crucial role in the establishment of a new smart cupboard in the kitchen by allowing the insertion of basic information about the new cupboard into the system, such as the number of shelves, its theme, associated user permissions, etc.

5.1.3 Cupboard Controller API

The Cupboard Controller component is the most vital component of the prototype for the accomplishment of all its actions. It is a Python-written Flask server that is responsible for reliable and efficient communication between the microcontrollers that activate the hardware parts (lights, motor, etc.) and the various different potential action requests by the user. In more detail, the server receives HTTP requests and analyses the request's URL to invoke the corresponding handler. The Cupboard Controller's handlers are grouped into the following seven categories based on the targeted cupboard sensor or part for activation: Camera motor, Vibration sensor, LED lights, Door motor, Scale, Proximity, and Touch sensor. Each handler in the Accessible Smart Kitchen Cupboard is responsible for constructing a specific command that is tailored to the appropriate microcontroller via serial communication protocol [34]. The microcontrollers, which are two Arduinos, are programmed to parse the received text-based command and use it to control the relevant sensor.

For example, if the user wants to check which products are about to expire in the kitchen inventory, they can use a voice command. The Inventory Backend receives the request, makes an HTTP request to the Cupboard Controller responsible for the cupboard hosting expiring products. The Cupboard Controller constructs a text-based command (e.g., "blink_interior_red_5") and passes it to the appropriate Arduino microcontroller. The Arduino parses the

command and fulfills the desired action, such as blinking the interior LEDs in red for 5 seconds to indicate items that are about to expire.

5.1.4 Redis Listener service

In the Accessible Smart Kitchen Cupboard, the communication between the Arduino microcontrollers and the Cupboard Controller is not just one-way, but rather a two-way mutual communication. The Arduino microcontrollers can inform the Cupboard Controller about any new event, such as a new item being placed on or off a specific scale, a touch event on the cupboard door, or a hand approaching the proximity sensor of a scale. The Cupboard Controller then publishes this information of the event to a local Redis server. Redis is a powerful Publish/Subscribe system that allows multiple clients to subscribe to channels and receive messages as they are published to those channels by publishers. The use of Redis ensures that the information about the events is accurately and efficiently communicated to the appropriate channels.

Furthermore, the Accessible Smart Kitchen Cupboard employs an Redis Listener service that subscribes to all the channels and waits for any of the three potential events to occur. Once an event is detected, the Redis Listener service makes the appropriate HTTP request to the Cupboard Controller to handle the event accordingly. The use of the Redis Listener service ensures that all events are quickly and accurately detected, and that the appropriate action is taken. With the two-way mutual communication and the use of the Redis Listener service, the Accessible Smart Kitchen Cupboard is highly efficient and effective in handling events in real-time, ensuring a smooth and seamless experience for users.

5.2 Database

A database is an organized collection of structured information, or data, typically stored electronically in a computer system [35]. It provides a mechanism for creating, retrieving, updating, and deleting data, and enables users and applications to access and manipulate data in a reliable manner. The Accessible Smart Kitchen Cupboard uses MongoDB which is a NoSQL document-oriented database and it is characterized with great scalability (it can scale up as more smart cupboards are added in the kitchen) and great performance allowing fast read and write operations. Another reason that MongoDB was chosen is that is easily integrated with other technologies and more specifically with the Python programing language that the backend services APIs are written at.

The MongoDB database plays a vital role in ensuring the appropriate functioning of the Accessible Smart Kitchen Cupboard. It serves as the centralized repository for all the necessary data required for inventory management in the kitchen. The database holds comprehensive information about the cupboards, including the number of cupboards available in the inventory. For each cupboard, the database maintains details regarding the number of shelves and their specifications, such as length and height.

Furthermore, the database keeps track of the availability of empty slots within each cupboard, allowing efficient utilization of storage space. For non-empty slots, the database stores information about the specific product stored, including its quantity or weight value, expiration date, an illustrative image representing its kind, and the exact position on the cupboard shelf. This detailed information enables accurate tracking and management of the stored items.

To ensure real-time updates, the database is constantly updated whenever a cupboard enters the scanning mode and the item detection algorithm runs. This update process includes modifying the positions of empty slots, updating weight values, and adjusting the positions of items stored within the cupboards. In addition to dynamic data, the database also stores essential static data required for the smart cupboard's functioning. This includes the predefined set of food items that the cupboard is trained to recognize, corresponding themes for each cupboard, and Redis parameters needed for each cupboard controller API, such as channel names and IP addresses.

5.3 In-Cupboard User Interface

A user interface (UI) is the means by which a user interacts with a software application, a hardware device or a system in general [36]. It includes all the visual and interactive elements, such as buttons or menus, that a user can use to insert the desired data. UI is an essential component because it determines the quality of the user experience, which can significantly impact how quickly and intuitively users interact with it.

The smart kitchen cupboard has an embedded 17cm x 11cm touchscreen display, located at the top of the upper shelf. The entire cupboard prototype is designed based on the 'design for all' approach. The same principle is applied to the touchscreen, which is properly tilted to be accessible and easy to use for people in wheelchairs. The touchscreen display constitutes both an input channel and an output channel as the user can see information about existing products but also perform various actions such as lighting a specific product or seeing statistics on the consumption or supply of a selected product in different time intervals.

The user interface (i.e., frontend) of the Accessible Smart Kitchen Cupboard was implemented using the Angular framework that offers rich user experiences, fast responsiveness, and code maintainability [37]. The main reasons for choosing that specific framework were its powerful routing system, which makes it easier to navigate between different parts of the application, and its use of the Model-View-Controller (MVC) programming pattern [38], which makes it easier to maintain and extend the application in the future.

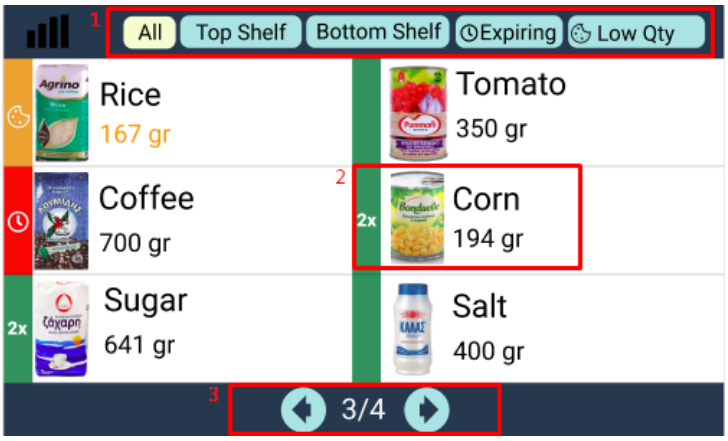

Figure 16 : Home page of Accessible Smart Kitchen Cupboard UI

The user interface is displayed on a titled touchscreen located at the top of the cupboard. On the homepage (**Fig. 16**), the user can view all the food items that are stored inside and obtain the current status of the cupboard. In the top bar of the homepage (**notation 1**), the user can filter the food items by various categories, such as those about to expire, those with a low quantity level, or by shelf position. For each displayed food item (**notation 2**), the user can see a related image, its quantity level in grams and a color-coded status indication (red for close to expiration, orange for low quantity or green for none of the above.) By checking the status of the cupboard, the user is able to consume

supplies that are close to expiration, reducing food waste or avoiding potential health issues by not consuming expired items. At the bottom bar of the page (**notation 3**), there are two back and forth navigation buttons allowing all the available stored items to be displayed.

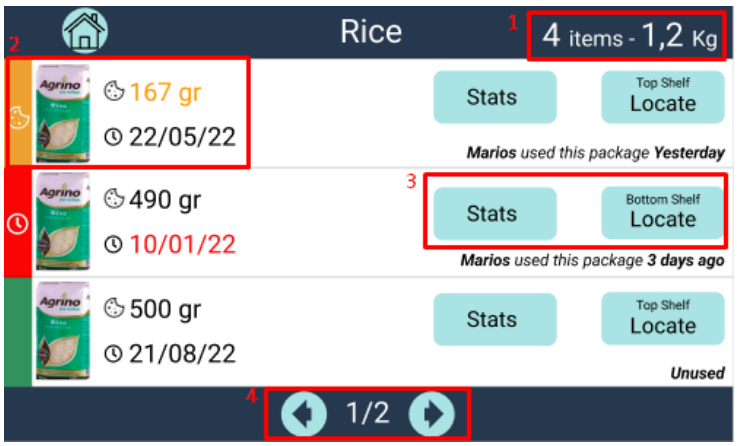

Figure 17 : Product page of cupboard's UI

By clicking on one of the displayed food items, the user is taken/navigated to the product page (**Fig. 17**). At the top bar of this page (**notation 1**), the user can check the total available quantity of the selected item and the number of total packages. In addition, the user can view the quantity level, expiration date, and check the indication status (**notation 2**) for each item of the selected product. This information is especially useful in cooking, as it allows the user to make informed decisions and choose the most suitable ingredients, which can significantly impact the outcome of the entire cooking procedure. The product page includes two buttons for each item (**notation 3**). One button is for highlighting its position within the cupboard, while the other button provides statistical information, offering valuable insights into usage patterns. If there are more than three items for the selected product, two back and forth navigation buttons appear in the bottom bar of the page (**notation 4**) to display the remaining items.

5.4 Voice-controlled service

The Voice API is essentially a third-part application that extend the capabilities of the Amazon’s virtual assistant, Alexa [39] . More detail, it is a custom Python-written API, in the ready-provided Alexa Skill kit platform, which implements all the functionalities that a user can invoke interacting with the smart kitchen about a specific smart cupboard or the entire kitchen inventory in general. For example, when a user gives a voice command to the Alexa device, the device records the audio input and sends it to Amazon's servers for processing. The audio is analyzed by Amazon's Alexa Voice Service (AVS), which uses natural language processing (NLP) algorithms to convert the user's spoken words into text. Once the user's voice command has been transcribed, the text is then sent to an Alexa Skill of the Voice API that is designed to handle the specific command by invoking the appropriate part of the Inventory Backend. The Voice API skill then processes the request and sends a response back to the device, which is read aloud by Alexa.

5.4.1 Voice service

The voice service component is an alternative input channel of the Accessible Smart Kitchen Cupboard. It allows users to interact with the kitchen inventory or only with one smart cupboard at their own will by predefined voice commands. The voice service is based on Alexa [39], Amazon’s voice assistant device, and it matches each user action intent with a voice command and handles it by interacting with the Core services of the Accessible Smart Kitchen Cupboard. Moreover, the voice service generates a dynamic response based on the data retrieved from the backend APIs and provides it to the user by announcing it loudly. Being informed audibly can be very useful, especially

in cases when the user’s hands are unavailable (e.g., washing hands) or vital and necessary for people with vision impairments who cannot get visible feedback.

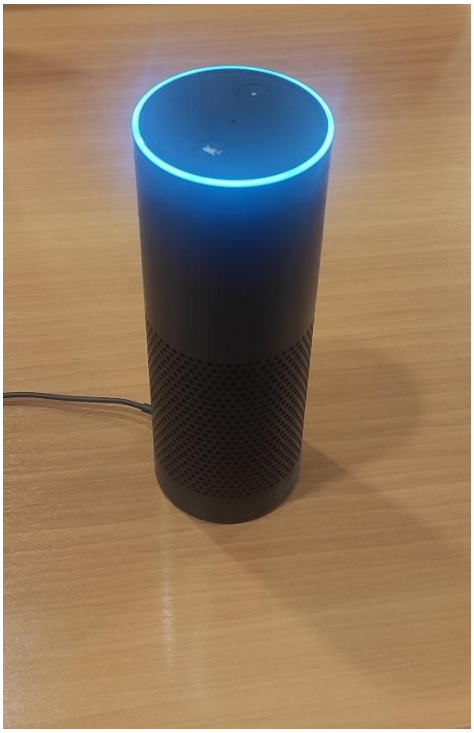

Figure 18 : Cupboard's voice-controlled device

Through voice commands, the user can easily retrieve information, locate products, and manage the cupboard's functionalities. Some indicative examples of voice commands and their potential responses that can be used to interact with the Accessible Smart Kitchen Cupboard are the following:

1. *"What products are about to expire?"*
    - **Response:** *"The products that are about to expire include mayonnaise, beans, and tomato cans. Please note that the specific expiration dates may vary."*

2. *"Where is the rice stored?"*
    - **Response:** *"The rice is stored in cupboard 2, on the upper shelf."*
3. "Which cupboards have available space?"
    - **Response:** *"Cupboard 3 and cupboard 5 currently have available space to accommodate additional items."*
4. *"Open cupboard 3."*
    - **Response:** *"Cupboard 3 is now open. How can I assist you further?"*
5. "Inform me about salt in cupboard 2."
    - **Response:** *"In cupboard 2, the salt package is located on the bottom shelf, next to the sugar and has 235 grammars.*
6. *"Where are the cans stored?"*
    - **Response:** *"The cans are stored in cupboard 2 and 3."*

5.5 Data flow paradigm

The following interaction paradigm will help the reader understand how the various components of the Accessible Smart Kitchen Cupboard are connected and how data flows through them, explaining the high-level architecture (Fig. 19). First of all, let's consider a user cooking in their smart kitchen who wants to know which food ingredients are close to expiring, so they can use them or not. The user asks the smart kitchen through their voice-controlled device which products are expiring in the kitchen inventory. The voice service handles the intent of the given voice command by invoking the corresponding endpoint of the Inventory Manager API with an HTTP GET request. The Inventory Manager is responsible for finding the expiring ingredients and their exact positions in the cupboard and storage spots. Then, the data passes from the Inventory Manager to the Cupboard Manager, which communicates with

the appropriate Cupboard Controller API to light up the LED stripes of the corresponding cupboard doors and items' stored positions with a red color. After the cupboards' doors have been lighted up, the APIs return an 'OK' response to the Inventory Manager, which returns a list of all the expiring products and their positions in the inventory, letting the voice service know this information. Finally, the voice service produces a clear and comprehensive response to the user's question, which is pronounced audibly by the voice-controlled device.

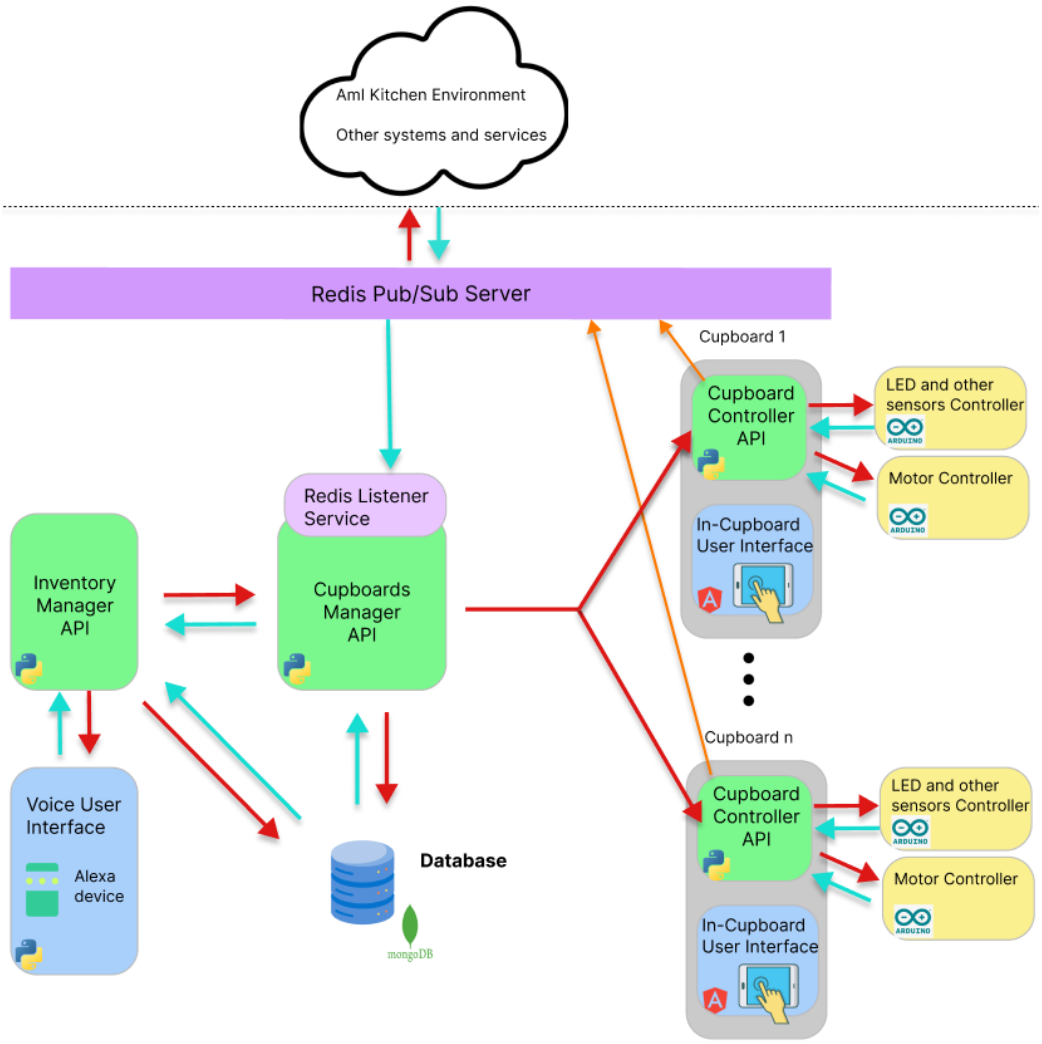

Figure 19 : High-level architecture of Accessible Smart Kitchen Cupboard

5.6 Item detection algorithm

The core intelligent of the Accessible Smart Kitchen Cupboard is based on its ability to recognize what kind of food item is stored inside. The cupboard can recognize the twelve following often used food items by using deep machine learning technology [40] [30] and more specifically by solving an image recognition problem :

- Corn can
- Mushroom can
- Tomato can
- Beans
- Salt
- Merenda
- Coffee
- Sugar
- Mustard
- Vinegar
- Rice
- Mayonnaise

Figure 20 : The twelve recognizable food products by the Accessible Smart Kitchen Cupboard

Image recognition is a subcategory of computer vision and artificial intelligence scientific fields and represents a set of methods for detecting and analyzing images to enable the automation of a specific task. It is a technology that is capable of identifying places, people, objects and many other types of elements within an image, and drawing conclusions from them by analyzing them. The image recognition in the cupboard's *Scanning Procedure* comes true by a small camera (see subchapter 3.3.1) that scans horizontally and gradually the two cupboard shelves.

The "Scanning Procedure" is a custom-made algorithm (Fig. 23) with the following execution steps. The camera begins its scanning route from its starting position (y = 0, x = 30), which corresponds to the right edge of the bottom cupboard shelf. The camera moves every 5 millimeters while scanning and flashes light so that there is enough brightness to capture an image by making an HTTP request to its API. The returned bytes are decoded, and the formed image is rotated clockwise by 90 degrees because the camera is placed vertically for practical spatial reasons. Next, having saved locally the information of the original width and height of the captured image, a laser line is drawn in the image which represents virtual scanning (Fig. 22). At this point, a ready code mobile object localizer[3] is invoked (Fig. 21) which always detects 100 entities by drawing a rectangle in the input image and assigns a probability score for each entity. For each of the 100 detected entities, the algorithm filters and keeps only those whose score is greater than the experimentally extracted threshold of 0.3 and whose drawn rectangle is not too

[3] https://tfhub.dev/google/lite-model/object_detection/mobile_object_localizer_v1/1/metadata/2

large compared to the initial dimensions of the input image (to eliminate the occasion that the localizer detected the whole image as one entity).

Figure 21 : Two products detected by the mobile object localizer.

After filtering the produced detected entities, the algorithm checks if the laser line is included inside one or more rectangles of the detected entities, making two cases. The first case is that the laser line found zero items, which means that a laser fail event occurred, and the camera moves to the next position. Otherwise, the algorithm crops and saves locally the rectangle image of the rightmost entity (as the camera moves to the left) and defines the starting point of the item as the current position of the camera. The ending point of the rightmost item is defined by the position of the camera, either in the first laser fail event or the first time that the laser line has crossed the right part of a new rectangle. The scanning procedure described above continues along the bottom shelf and when it is over, it repeats the same process on the upper shelf.

Figure 22 : The camera detected a tomato can (Left) and a mushroom can (Right). The lazer detector line (Red) is included only in the mushroom's white rectangle that's why the image of the right product will be the only one that would be cropped and saved locally. As the camera moves, the red line will keep scanning to the left the rest of the stored products.

After saving many locally cropped images for every food item stored inside the smart cupboard, the algorithm provides the images of each distinct item to a pre-trained CNN deep learning model. This model then determines which of the 12 possible classes the item belongs to. Finally, the algorithm creates a JSON file summarizing the information for each item, including its kind, starting position, ending position, and quantity measured by the corresponding scale. The JSON file is stored in the Mongo Database.

Algorithm: Item detection algorithm

Input: Images of stored food items

Output: Update database with information for every stored food item

Initialization of variables: assign zero *to lazer detected items* variable

For each shelf do: // Start scanning from the bottom shelf
    For x_camera = 0 until x_camera = 380 with step 5mm do: // Move camera by 5mm
        Make an HTTP GET request to camera's API to capture an image
        Decode image's received bytes
        Rotate image 90° clockwise // Camera is not placed straight for practical reasons
        Draw a lazer line vertically in the middle of the captured image
        Invoke object localizer[3] // Produces 100 detected entities
        For each one of the 100 detected entities: // Apply filtering
            If entity score > 0.3 and cropped image is smaller than the original:
                Keep this entity
        end
        lazer detected items ← Count the total number of filtered entities that their rectangles are crossed by the lazer line
        If lazer detected items = 0: // Lazer failed event
            Continue to next loop iteration // Move camera to next position
        Else: // The lazer line scanned one or more food items rectangles
            item_start_position ← Current camera x position of first-time entity detected
            item_end_position ← The camera x position either in the first laser fail event or the first time that the laser line has crossed the right part of a new rectangle.
            Crop and save locally the image of the rightest entity
    end
end
For each distinct food item found inside the cupboard:
    Provide its cropped images as input to a pre-trained CNN model
    Classify food item to one of the 12 known classes
end
Create a JSON file with the summarized learned information
Update the Mongo database based on the produced JSON file

Figure 23: Item detection algorithm

Chapter 6

Cognitive Walkthrough Evaluation

Evaluating a particular system entail determining how effective it is based on set standards for analysis. The aim is to identify weak spots or potential issues that could affect the optimal performance of the system by subjecting it to various tests with predefined criteria. Evaluation is crucial in ensuring that a system is meeting its intended goals and objectives and is performing optimally. Overall, evaluation plays a critical role in the development and maintenance of a system, helping to ensure that it remains relevant, effective, and efficient over time.

The evaluation procedure of the Accessible Smart Kitchen Cupboard included a cognitive walkthrough evaluation [41] which included four multi-experienced User Experience (UX) experts from the FORTH HCI laboratory[4]. The cognitive walkthrough technique is employed to assess the overall user interface of a system, focusing on users' initial experience without formal training. Its main objective is to determine the ease with which users can perform specific tasks within the system. Due to its emphasis on small tasks, the cognitive walkthrough is considered one of the quickest forms of usability testing. This evaluation can be conducted prior to system development and during the design phase. The aim of this assessment was to identify potential issues with the concept, uncover any unsupported features, and detect usability

[4] https://www.ics.forth.gr/hci/hci-people

errors by gathering expert feedback before planning a larger user-based evaluation.

6.1 Process

Throughout the experiment, a conductor assisted the users (UX Experts) in navigating through a sequence of tasks and posed a specific set of questions to assess the ease of interaction with the Accessible Smart Kitchen Cupboard. The conductor observed the users' actions and took notes on whether they attempted and successfully achieved the desired outcome, whether they perceived the availability of the correct action, and whether the outcome matched their expectations. At the conclusion of the experiment, the conductor documented the steps that appeared to confuse the users, as well as any issues that arose.

After having informed and presented all the functionalities of the Accessible Smart Kitchen Cupboard to the four UX experts, they were encouraged to feel comfortable interacting with the prototype as they saw fit. The experts then interacted with the smart cupboard and were asked to take down some notes focusing on potential detected issues and improvement suggestions.

6.2 Results

All four experts came to the conclusion that the Accessible Smart Kitchen Cupboard provided high-quality functionalities, efficiently supported inventory management, and could be a helpful asset when interoperating with the intelligent kitchen in cooking procedures. They noted that their interaction was conducted seamlessly, mentioning that they felt confident about the

satisfaction of their intended actions as they always received appropriate and indicated feedback.

The most remarkable and noteworthy issues that were detected by the evaluation process and resulted in feedback for the ongoing implementation of the prototype, along with their solutions, are presented below:

Issue 1: The Accessible Smart Kitchen Cupboard has encountered an issue regarding its inner lights. The LED strips within the cupboard diffuse the light, making it difficult to clearly distinguish individual food items. This poses a challenge for users seeking specific items when there are similar food items next to them, making it difficult to determine the desired item.

Solution: The solution to this unwanted situation is to enhance the lights by making them more directional and intense. By doing so, the light will be better focused, effectively pointing out the slots of each cupboard shelf, ensuring greater visibility and ease of use for users.

Issue 2: One additional issue arises when users engage with the voice commands and interact with the voice-controlled service. During this process, their attention and gaze are naturally directed towards the voice-controlled device, causing them to overlook the visual color-coded notifications provided by the external lights on the cupboard doors. As a result, they miss out on important visual cues that aid in identifying specific items within the cupboard.

Solution: To address this issue, a solution is to incorporate an auditory notification response within the cupboards themselves. By doing so, users would be prompted to direct their attention towards the furniture, ensuring

they do not miss any essential notifications while interacting with the voice-controlled service. Furthermore, conducting research to determine the optimal position for the voice-controlled device within the kitchen will help to find a balance where the device can effectively accept voice commands without distracting the user's attention away from the visual cues provided by the cupboard doors.

Issue 3: The Accessible Smart Kitchen Cupboard lacks of a stop or cancel mechanism when the cupboard door is opening or closing. This poses a significant inconvenience for users, especially when they have already opened the cupboard and are interacting with the touchscreen UI. In such situations, accidental contact with the cupboard door causes it to close abruptly, obstructing the user from continuing their interaction with the screen.

Solution: To provide a solution to this issue, the Accessible Smart Kitchen Cupboard will incorporate a sensor that can detect an opposite direction force. By doing so, the sensor would be able to detect when users opposes the movement of the cupboard door by pressing it with their hand, signaling the need to stop the door movement and return to its last position. This approach would allow users to conveniently and effortlessly halt the cupboard door's motion using their hands, eliminating the frustration caused by accidental closures and ensuring a smoother and more user-friendly experience overall.

Issue 4: The user interface of the Accessible Smart Kitchen Cupboard received some negative comments and observations from UX experts. Specifically, they pointed out issues such as poor color contrast, which can make it difficult for users with visual impairments to navigate the interface effectively. Additionally, the small size of fonts assumed that would be challenging for users with limited vision, requiring them to strain their eyes to

read the text. The experts mentioned that the number of clicks needed to press the Locate buttons should be decreased as lighting up a desired item is a crucial feature. Furthermore, experts recommended bringing expiration date information to the homepage for quick reference, as navigating through multiple screens to access this crucial information could be inconvenient. Lastly, the small size of the screen was identified as a limitation, with experts suggesting that a larger screen would provide a more user-friendly experience.

Solution: To address the feedback and ensure inclusivity, we will undertake a comprehensive redesign of the user interface for the Accessible Smart Kitchen Cupboard. Our primary focus will be on enhancing accessibility for all users. As part of this redesign, we will increase the font size to improve readability, implement more comprehensible icons for intuitive navigation, and improve the color contrast to accommodate users with visual impairments. Additionally, we recognize the importance of a larger screen size, and as a result, we will expand the display to provide a better experience for everyone.

Issue 5: Another emerging issue identified by experts was the limited interaction when using voice commands to check the empty available space in the kitchen inventory. They suggested that the voice-controlled service should provide a dialogue that assists the user in locating empty slots, rather than relying on a single command that may be easily forgotten.

Solution: To address this issue, the solution entails enhancing the voice-controlled service to support multi-turn conversations with users, extending beyond just the kitchen inventory management assistance. By implementing this improvement, the Accessible Smart Kitchen Cupboard will offer a more comprehensive and interactive experience through voice commands. Users

will be able to engage in natural and fluid conversations, accessing all the features of the smart cupboard with ease.

In addition to addressing the aforementioned issues, UX experts have highlighted several notable features of the Accessible Smart Kitchen Cupboard that greatly enhance its innovative nature and usefulness. The features that got the most positive comments are the following ones:

Feature 1: The experts recognized the tremendous usefulness of the feature that allows users to illuminate items inside the cupboard. They emphasized that this functionality greatly aids users in distinguishing between two similar food products, such as rice for soup and rice for risotto, thereby preventing potential cooking mishaps. Moreover, this feature is expected to significantly reduce search time, particularly for individuals facing difficulties with bending down. Additionally, it serves as a valuable assistance for individuals with visual impairments, as well as those from different countries who may be unfamiliar with the packaging of various products.

Feature 2: Another feature that captured the interest and appreciation of the experts is the cupboard's ability to open halfway, allowing users to interact with the touchscreen user interface before fully opening the kitchen cupboard. They remarked that this feature enables users to quickly check which products are stored inside, eliminating the need to visually inspect each item on the shelves. Furthermore, this functionality will be even more useful if the kitchen storage places scale up and become taller or deeper. In the case of wheelchair users, the partially opened cupboard presents no obstacle, as it only opens a few centimeters, ensuring easy accessibility and usability.

Feature 3: The experts praised the ability to check expiring products through voice commands, noting its positive impact on user experience. They

highlighted that this feature saves users valuable time, eliminating the need to search through every cupboard or even when they are away from the kitchen. Additionally, it mitigates the frustration and inconvenience of manually searching for expiration dates on product labels. This functionality proves beneficial not only for individuals with mobility issues who would otherwise have to conduct unnecessary searches in the cupboards but also for anyone engaged in cooking activities within the kitchen.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

The current thesis work has presented the Accessible Smart Kitchen Cupboard, an accessible, innovative, multi-modal, multisensory prototype that has been designed to help people store and manage their food ingredients more efficiently, while also providing valuable information and guidance for cooking procedures and inventory management. The main goal of the smart kitchen cupboard is to revolutionize the way people interact with their domestic kitchens, making their lives easier and more comfortable.

One of the most remarkable features of the Accessible Smart Kitchen Cupboard prototype is considered to be its accessibility. It has been designed based on the principles of design-for-all [27], which means that its final target user group is not limited but extends also to people with disabilities, such as those with motion, hearing, or vision impairments, or elderly people with mild cognitive issues. This inclusive approach is a significant step forward in the vision of creating a more accessible kitchen environment where automated assisted tasks occur without obstacles or frustration.

Apart from accessibility, the smart kitchen cupboard has several other high-tech features to make our small tasks in the kitchen area easier and more efficient. First of all, it can indicate the position of one or more stored items, making it easier and quicker for users to locate and use them. Moreover, the

cupboard is able to recognize its available empty space and guide the user accordingly in the procedure for storing food packages and general inventory management. In addition, the cupboard provides detailed information on each stored ingredient, such as the expiration date, quantity, and last time used. This information helps users to be more effective while cooking, reduce food waste, and save money.

Based on the experiment we conducted with users, we have concluded that the smart kitchen cupboard can satisfactorily meet the needs of people with disabilities. The prototype has proven to be a valuable asset in assisting with cooking, managing inventory, and simplifying and automating daily tasks in the kitchen area. Furthermore, the voice commands, as an alternative input modality, were really appreciated by all participating users, especially those with motion or vision difficulties. In summary, the results of the experiment were highly encouraging, making us believe that this research can be developed into a commercial product with a positive impact on people's lives and produced on a large scale.

7.2 Future work

The future work of this thesis involves the implementation of a comprehensive user interface for the entire kitchen inventory that will be designed based on the existing database architecture. The user interface will help users keep track of their food products, expiration dates, and storage space. The interface will inform users of the location of food products that are about to expire or have a low quantity, enabling them to plan their meals accordingly. Additionally, the user interface is intended to provide basic information about every smart cupboard in the kitchen, including its theme, door status, and the number of

available free spots. This will make it easier for users to find the items they need and manage their storage space effectively.

Additionally, our future plans include conducting an extensive user-based evaluation. This evaluation will include individuals of diverse ages and capabilities, encompassing those with vision, motion, hearing impairments, as well as elderly individuals. By incorporating a wide range of users, we wiil be effectively able to measure the accessibility levels of the Accessible Smart Kitchen Cupboard and assess its usefulness for people from all walks of life. This user-based evaluation will provide valuable insights into the strengths and weaknesses of the Accessible Smart Kitchen Cupboard design and functionality, enabling us to make informed improvements and ensure its usability for everyday individuals.

Another important aspect of the future work is the ability to insert new user access authorizations, enabling parents to control their young children's access to certain parts of their kitchen inventory ensuring their safety and protection from harmful content such as sharp knives or detergents. Also, with new user access authorizations, hosts can grant their guests temporary access to certain kitchen cupboards while keeping some of their personal data confidential.

Last but not least, an obvious improvement that could be made is an extension of the knowledge base of the cupboard. Currently, the smart kitchen cupboard is only able to recognize 12 basic everyday food items that are commonly used. However, as it is apparent, a kitchen cupboard can store many different kinds of items, such as cereals, spices, jams, and others. Therefore, the cupboard must be progressively trained with more groups of products, and at each stage of training, the learning accuracy of each step must remain above a satisfactory, predefined threshold, with no conflicts or false positives.

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Appendix I.

Acronyms

AI	Artificial Intelligence
AmI	Ambient Intelligence
API	Application Programming Interface
AVS	Amazon Voice Service
CNN	Convolutional neural networks
HCI	Human Computer Interaction
HTTP	Hypertext Transfer Protocol
I/O	Input/Output
IMU	Inertial Measurement Unit
IoT	Internet of Things
JSON	JavaScript Object Notation
LED	Light Emitting Diode
MVC	Model-View-Controller
NLP	Natural Language Processing
PCB	Printed Circuit Board
PIC	Programmable Intelligent Computer
RFID	Radio Frequency Identification
UHF	Ultra-High Frequency
UI	User Interface
UX	User Experience