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Seemless-Kitchen: A Multimodal Cooking Support System for the Visually Impaired

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People with visual impairments (PVI) face significant barriers in independent cooking due to fragmented assistive technologies. We present Seemless-Kitchen, a multimodal information system integrating NFC-enabled meal kits with Large Multimodal Model (LMM)-based Voice Assistance (VA). Through iterative user-centered design, we developed a comprehensive framework addressing seamless physical-digital integration and adaptive personalization. Our design demonstrates effectiveness in prototype evaluation and establishes new paradigms for accessibility-focused multimodal information systems.

Keywords—People with Visual Impairments (PVI), Assistive Technology, Voice Assistant (VA), Meal preparation, Multisensory

I. Introduction

Cooking is a vital aspect of daily life that fosters independence, self-efficacy, and dignity. However, for people with visual impairments (PVI), preparing meals independently remains a persistent challenge. Barriers such as difficulty accessing expiration dates, identifying ingredients, and safely managing cooking tasks often lead to reliance on caregivers or packaged meals. These workarounds may undermine autonomy and contribute to poor nutrition and reduced self-esteem [1, 3, 4, 15].

At the same time, nearly 49.6% of PVI express a strong willingness to cook independently, highlighting a clear yet unmet demand for systems that support accessible, confident, and self-directed cooking experiences [1]. Existing services fall short in addressing critical needs such as accessing essential food information (e.g., expiration dates or allergens), navigating complex cooking procedures, and receiving adaptive, real-time guidance [1, 8].

To address this gap, we introduce Seamless-Kitchen, a multimodal information system designed to empower PVI to cook with greater independence. Our approach integrates NFC-embedded meal kits with a Large Multimodal Model (LMM)-based voice assistant (VA) capable of contextual tracking, non-linear dialogue, and multisensory guidance. This paper presents the system's design rationale, user-centered development process, and anticipated impact, demonstrating how Seamless-Kitchen enables PVI to engage with cooking in a more autonomous, accessible, and confident way.

II. Related Work

A. Meal-preparation Experience

PVI face two primary challenges in cooking: accessing essential information and navigating the cooking process [4]. The first challenge involves difficulties in understanding recipes and verifying expiration dates, which may lead to using expired food or incorrect ingredients [1, 9, 12, 13]. The second challenge concerns the complexity and risks of cooking tasks such as ingredient preparation, frying, and boiling. Survey data highlights that peeling vegetables (82.1%), frying foods (72%), and slicing ingredients (50%) are particularly difficult for PVI [1, 8, 10, 12]. Additionally, preparing dinner can take up to two hours for PVI, showing the considerable effort involved [3].

B. Current Solutions and Limitations

Existing assistive technologies address specific aspects of meal preparation but lack comprehensive integration. Camera-based technologies like Chat-GPT 4.0, Sullivan (SKT+), and QR code systems provide food product information but require precise positioning and clear picturing that can be challenging for PVI [6, 13]. VAs such as Siri, Yes-Chef, and Cooking Without Looking offer recipe guidance but rely on rigid, sequential communication that limits dynamic adaptability during cooking [1, 8, 14]. Physical supports including Braille cookbooks, educational programs like The Blind Kitchen, and specialized safety tools address specific challenges but provide fragmented support, which lacks consistency through the meal preparation process [10]. Current solutions fail to provide integrated support across information access, ingredient preparation, and cooking guidance stages. The fundamental limitation lies in the lack of seamless integration between physical cooking objects and accessible digital information systems.

III. USER-CENTERED DESIGN RESEARCH

A. Research Methodology

To validate the problem, we conducted two rounds of interviews with four PVI and two caregivers (see Table 1). Participants were recruited through online outreach. The first round explored needs and validated our initial concept, while the second round evaluated our low-fidelity prototype. Interviews were recorded, transcribed, and analyzed using thematic analysis to identify recurring themes that directly.

TABLE I. Interviewees Profile

Participant	***Visual Impairment Description***	***Age***	***Experience Using Assistive Technology***
P1	Legally Blind, Acquired	30s	Yes
P2	Legally Blind, Acquired	20s	Yes
P3	Legally Blind, Acquired	30s	Yes
P4	Legally Blind, Congenital	30s	Yes
P5	Caregiver	30s	-
P6	Caregiver	30s	-

B. Key Findings

Challenges in Meal Preparation: Participants identified significant barriers across three stages: accessing information, managing ingredients, and cooking execution. Information access challenges included difficulty checking expiration dates and assessing freshness, with P1 describing it as "nearly impossible" and P4 sharing similar frustrations. Ingredient management posed additional challenges, as P4 noted: "Family members and acquaintances must regularly inspect and organize ingredients." During cooking, participants struggled with ingredient identification and measurement, with P2 highlighting: "I struggle to differentiate sauces and adjust portions accurately." These challenges often lead to increased reliance on convenience foods, negatively affecting nutritional balance.

Technology Preferences and Limitations: While participants acknowledged that camera-based assistive technologies improve accessibility, they highlighted significant usability constraints. P1 described QR code challenges: "Finding the exact location is challenging, and recognition varies with ambient lighting, making it almost impossible to do alone." P4 added: "Using a camera to photograph objects creates unnecessary complexity in daily life." All participants expressed a preference for voice-based assistance due to immediacy and hands-free operation. However, current VAs lack contextual awareness, with P3 noting reliability issues in receiving accurate, timely voice-based information. Additionally, P4 indicated that visual impairment exists along a spectrum -- from low vision to total blindness -- but existing technologies rarely adapt to these varying levels of need.

Cooking as Independence and Social Connection: Participants emphasized cooking's crucial role in enhancing independence and quality of life. P1 explained: "Successfully preparing meals helps redefine disability perceptions and builds self-esteem," while P3 emphasized that "independent cooking increases the sense of achievement and creates attachment to self-prepared food." Cooking also strengthens social relationships, with P3 expressing desire to "cook directly for family" and P4 sharing aspirations to "connect better with others through shared cooking and dining experiences."

C. Design Requirements

Based on these findings, we identified three critical design requirements: (1) seamless physical-digital information bridging without complex camera positioning, (2) context-aware, non-linear voice interaction supporting dynamic cooking workflows, and (3) adaptive personalization addressing diverse visual impairment levels and technological literacy. These requirements guided the development of our integrated NFC-LMM system architecture.

IV. SYSTEM DESIGN

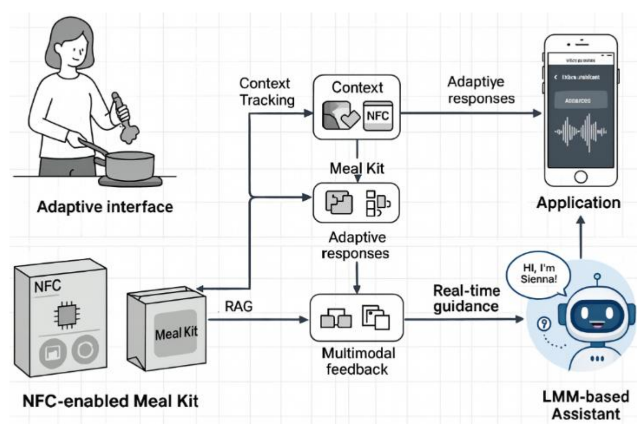

Fig. 1. System Architecture of the Voice-Guided Cooking Assistant

A. System Concept and Design Rationale

Seemless-Kitchen is a multimodal cooking assistance system in which a VA and a PVI user interact in real time, while the meal kit serves as a physical interface that minimizes tactile and visual barriers throughout the cooking process (see Fig. 1). It integrates NFC-enabled meal kits with an LMM-based VA to address the comprehensive challenges identified in our user research. We selected meal kits as the foundation because they simplify cooking by reducing complex preparation steps, offering pre-portioned ingredients, and providing clear, nutritionally balanced recipes [5, 11]. This approach directly addresses PVI challenges in ingredient management and measurement accuracy while reducing cooking complexity. The VA complements meal kits by delivering step-by-step auditory guidance, reducing the need for physical manipulation and enhancing overall ease of use [1, 8].

The system architecture centers on context bridging, where NFC tag recognition triggers contextual activation of the VA, providing comprehensive meal information and cooking guidance. Each meal kit features strategically placed NFC tags that serve as information gateways, enabling users to access ingredient details, expiration dates, allergen information, and cooking instructions through simple touch-based interaction.

B. Context-Sensitive VA

Our VA, implemented using OpenAI's Realtime API, provides contextual awareness that distinguishes our approach from existing rigid, sequential systems. Unlike traditional VAs that require users to navigate through predetermined dialogue trees, our VA continuously tracks the user's current cooking stage and enables real-time, situational-aware responses. For instance, when a user asks "What was the expiration date?" while washing ingredients, the VA responds with the relevant expiration date and smoothly transitions to the next cooking step. This contextual intelligence is powered by Retrieval-Augmented Generation (RAG) technology using the LangChain framework, which pulls key information directly from a structured database such as recipes, expiration dates. This enables non-linear support, which is especially useful to the PVI who often need to revisit previous steps [7], ask spontaneous questions, or clarify details during complex cooking tasks.

C. Multisensory Integration Framework

Recognizing that PVI excels at utilizing non-visual sensory modalities, our system design is grounded in Multisensory Integration theory, which demonstrates that combining inputs from multiple senses enhances cognitive understanding and task performance accuracy [2]. By integrating auditory, tactile, thermal, olfactory, and spatial information, we compensate for the lack of visual cues while improving overall user experience and cooking confidence.

Temperature and Material State Detection: The system guides users through temperature sensing by integrating thermal perception (hand positioning above the pan), auditory cues (listening for 'tsk' sound when water drops hit the pan), and spatial awareness. For ingredient state changes, users rely on auditory feedback (changes in sizzling sounds), olfactory information (emerging aromas), and tactile feedback (texture changes when touched with utensils).

Kitchen Space Recognition and Ingredient Location Memory: Recognizing that PVI excels at spatial structure understanding [2, 16], the system confirms user location and provides context-aware guidance. To address ingredient placement memory challenges during cooking, the system guides initial ingredient arrangement in cooking sequence order, then references this familiar layout during instruction. This approach strengthens users' mental mapping of kitchen space while building cooking confidence.

D. Adaptive Personalization Design

To address diverse user capabilities identified in our research, we developed a systematic personalization framework based on visual impairment level and Braille literacy, as shown in Table 2. The system employs progressive information delivery, prioritizing two primary information channels initially, with supplementary information available upon request to reduce cognitive load while ensuring complete information access when needed.

Information Modality	***Totally Blind, Non-Braille***	***Totally Blind, Braille-literate***	***Low Vision, Non-Braille***	***Low Vision, Braille-literate***
Embossed Numbers	●	○	●	○
Braille Labels		●		●
High Contrast Colors			●	●
Tactile Properties	●	●	○	○

TABLE II. Package Information Accessibility Matrix

Our design process involved systematic iteration based on user feedback to optimize both NFC accessibility and meal kit usability (see Fig. 2).

NFC Tag Design Evolution: Initial designs placed NFC tags centrally on cardboard boxes, but user testing revealed location difficulties. P4 noted: "It is difficult to locate the NFC tag by touch," while P2 suggested: "It would be better if the mobile phone could be placed on a flat surface to scan the NFC tag." The second iteration addressed these concerns by adding an embossed frame around the centered tag, enhancing tactile identification while ensuring chip protection during delivery.

Meal Kit Packaging Optimization: Initial designs used Braille number stickers for ingredient identification, but user feedback revealed varying Braille literacy levels. P4 observed: "High-contrast colors are more helpful for people with low vision," and P1 noted: "Many visually impaired individuals cannot read Braille." The refined design incorporated high-contrast colors and large numbers for low-vision users while retaining Braille numbers and adding embossed relief for universal accessibility.

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Fig. 2. *Iterative Improvements in NFC Tag and Meal Kit Ingredient Packaging Design*

Voice Interaction Refinement: Early prototypes used ambiguous prompts like "Let me know when you're done," but user feedback highlighted the need for clearer interaction boundaries. We introduced step-by-step earcons (i.e., distinctive, non-verbal auditory cues) to mark the beginning and end of each cooking step, providing users with immediate auditory feedback for progress recognition.

V. CONCLUSION AND LIMITATIONS

This study proposed a novel service to assist visually impaired individuals in independently preparing meals by integrating a VA with accessible meal kits. By combining technologies such as NFC and multisensory feedback, the system addressed key challenges faced during meal preparation, including accessing information and managing cooking progress. In particular, multisensory interaction -- combining auditory, tactile, and spatial cues -- proved essential in supporting users without relying on visual input. The iterative design approach, supported by user feedback, demonstrated that leveraging non-visual sensory modalities can significantly enhance user experience and promote independence.

Despite its contributions, the current system remains limited in several ways. Its scope is confined to the context of meal kits and does not fully resolve challenges in the broader cooking environment. For example, the absence of vision-based input prevents the system from detecting unexpected events such as spills, misplaced items, or hazards that require visual awareness. In addition, while personalization strategies were explored, long-term user adaptation and accessibility across different kitchen layouts remain areas for further development.

While the current focus of Seemless-Kitchen is on structured cooking tasks, the underlying design principles may also be applicable to other domains where non-visual interaction and physical-digital integration are essential (e.g., healthcare, education). By continuing to explore new possibilities, this service has the potential to evolve into a comprehensive solution that empowers visually impaired individuals in the kitchen and beyond, promoting independence, inclusivity, and connection in everyday life.

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