International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. 15, No.1 (Mar-24)

http://dx.doi.org/10.12785/ijcds/150199

Approximate Computing-based Assistive Shopping Trolley for Visually Challenged People

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Received 7 Feb. 2024, Revised 10 Mar. 2024, Accepted 11 Mar. 2024, Published 15 Mar. 2024

Abstract: Sighting is one of the five senses that help us to live in this world. According to the World Health Organization (WHO), more than 2 billion people encounter vision challenges that inflict severe life problems. The visually challenged people must utilize their senses, i.e., touch, smell, taste, and sound, to perform their daily tasks. Visually challenged people suffer from visual impairment, either partial or total. Their therapy could be corrective eyeglasses, assistive devices, and medical treatment. In this work, we target an assistive device, i.e., we propose, design and implement an approximate computing-based smart shopping cart for visually challenged people. The proposed assistive shopping cart utilizes the Internet of Things (IoT), e.g., Radio Frequency Identification (RFID) sensors, an Infrared (IR) Sensor, and an Arduino microcontroller. The audio was employed during the shopping journey to notify the shopper of his current location in the mall, the name and price of each item he scans, and other information about the product that is written on the package. Combining many features in a single cart will result in a revolutionary device that might revolutionize the face of shopping for the visually impaired. The proposed cart improvements include obstacle detection, voice commands, and emergency assistance. The designed cart emphasizes the potential of technology to bridge barriers and empower people with disabilities, as well as the beneficial influence that inclusive solutions may have on overall quality of life.

Keywords: Assistive Technology, Approximate Computing (AC), Visually Impaired, Embedded System, Internet of Things (IoT), RFID, Obstacle Detection

1. Introduction

People rely on their five primary senses, i.e., touch/contact, sight/eye, hearing, smell and taste, to communicate with the outside world. When somebody loses a sense, it is trivial to utilize other senses to compensate for the knowledge that he gains from the missing sense [1]. Visually challenged persons suffer from visual impairment, which implies a partial or complete inability to perceive visual stimuli. Partial deficiency is known as *poor vision* and absolute inability is known as *blindness*. Because there are few treatments available, such as corrective eyeglasses, assistive devices, and medical therapy, visual impairment can make it difficult to do everyday tasks like reading and walking [2]. The World Health Organization (WHO) assesses that 2.2 billion individuals suffer from vision challenges. On the other hand, vision impairment imposes a significant financial burden on the worldwide economy, with an estimated yearly cost of $411 billion. Vision loss may affect persons of any age, where the majority of patients with visual challenges and blindness are older than 50 years [2].

Vision, the most powerful of our senses, is essential in all aspects and stages of our existence. Without vision, it is difficult to learn, walk, read, and participate in school, work, and social life. Vision challenges arise when an eye issue interferes with the visual system and its functioning. People who live long will conceive at least one eye disorder that needs proper remedy [3]. Globally, the foremost reasons for visual challenges include refractive errors, cataracts, diabetic retinopathy, glaucoma, and age-related macular degeneration [4]. The causes of vision problems differ substantially between and within countries, depending on the availability of eye care facilities, their cost, and the population's level of education. For example, low- and middle-income countries have a higher share of vision impairment due to untreated cataracts. Glaucoma and age-related macular degeneration are more common in countries with higher wealth [5].

People with visual impairments are unable to properly recognize their surroundings. They cannot thoroughly shop for the products they demand in their daily lives [6]. Shopping is a popular hobby among regular people. However, visually challenged people will be unable to appreciate this since they may struggle to distinguish items and safely navigate the supermarket aisles. These aisles operate as obstacles, making it harder for visually challenged persons to access them [7]. The store may include different divisions, including fruits, vegetables, canned foods, drinks, bakery, fitness and health-care products. Thus, visually challenged people must be able to correctly identify each section.

Based on a study that was conducted in Jordan and aimed to analyze the reality of persons with disabilities, i.e., functional difficulties, there is an individual with a disability/difficulty at a percentage of 11.1% among people aged 5 years and over in Jordan. The most common disability among Jordanians aged five and above is *visual impairment*, i.e., the difficulty of vision, with a prevalence of 6.0%, followed by motor disability, i.e., the difficulty of walking, at 4.8% and auditory impairment, i.e., the difficulty of hearing, at 3.1% [8]. Thus, in this work, we target visual impairment disability since it is the most common among people.

Assistive Technology (AT) is any hardware, software or system that delivers solutions to daily activities. It can enhance, advance and support the functional capabilities of people with complex needs [7]. A recent study [9] looked into how Jordanian instructors perceive assistive technologies for pupils with visual impairments. They identified many problems that instructors notice when utilizing assistive technology with their learners, including computer use, a child's readiness to utilize a particular device, a lack of these technologies and training in school and home. The conclusions emphasize perceived external hurdles to the efficient use of assistive technology, such as economic constraints, practice, societal views, and family support. Assistive technology tends to have negative impacts, which introduces ethical concerns since it might expose kids with visual challenges to unfavourable societal views, addiction, bullying, misuse, and extremism.

The authors of [10] sought to understand the key challenges that students with vision challenges confront when assistive technology is deployed in the Jordanian context. They discovered that the hindrance level is medium, with the most significant challenge facing pupils being a lack of time while utilizing assistive technologies in the classroom. Other factors have a major impact, such as parents' lack of awareness of Information and Communications Technology (ICT) and the family's ability to afford such equipment. Finally, the research emphasized the need for communication and collaboration between the Ministry of Education and training programs for families, students, and instructors.

Sensory aids for visually impaired people include hearing aids, visual alerting systems, Braille, and voice output devices. In this study, we presented an approximate computing-based smart shopping cart to help visually challenged persons solve the issues they have when shopping, such as:

- *Inadequate Assistance*: Visually impaired customers may struggle to acquire assistance from store employees when they want instructions or product information, and they may be subject to staff fraud.
- *Accessible Store Design*: Many malls and shopping stores have complicated layouts with congested aisles, making it difficult for blind persons to navigate freely.
- *Inaccessible Product Information*: Visually impaired individuals often rely on traditional aids such as posters, packaging, or displays to obtain product information. Without alternate forms such as braille, uppercase letters, or audio explanations, people may struggle to obtain important information about items, pricing, or ingredients.
- *Lack of Accessible Payment Systems*: Some payment systems may not be designed to satisfy the necessities of visually challenged people, making it difficult for them to complete transactions independently.

A smart shopping cart should address these challenges by providing features including voice assistance, obstacle detection, product inspection capabilities, and integration with accessible and secure payment systems. The objective of this work is the design and implementation of a smart shopping cart for visually challenged people. The cart aims to enhance their independence and range of motion while exploring places like shopping malls and supermarkets. The cart has sensors that may identify obstructions in the user's route, such as other shoppers or misplaced items. The cart helps the user navigate through the store by offering verbal advice. It allows them to easily find departments, goods, and checkout locations. The cart can be used to acquaint the user with the items on the shelves. It may audibly transmit product information, such as names, pricing, and other pertinent facts, allowing the user to make informed purchase decisions. Additionally, the cart includes an emergency button or the ability to alert store personnel or caregivers.

The rest of the paper is arranged as follows: Preliminaries, i.e., Internet of Things, assistive technology, and approximate computing, are clarified in Section 2. Then, Section 3 presents the related work while the architecture and the implementation details of the proposed cart are described in Section 4. The evaluation of the suggested system is explained in Section 5. Finally, Section 6 concludes the work while highlighting future directions.

2. Preliminaries

In this section, we provide a brief description of various technologies that are required to understand the context of this work, i.e., Internet of Things, Assistive Technology, and Approximate Computing.

A. Internet of Things (IoT)

It is an evolving paradigm that provides a plethora of novel applications for the next generation of technological breakthroughs. IoT applications are practically unlimited, allowing for seamless interaction between the cyber world with the real world [11]. The Internet of Things (IoT) is a system of networked equipment that can receive and transmit data across a network of radio waves without any human intervention [12]. IoT is a computational notion that describes how common physical goods may be connected to the internet and identify themselves to other devices, allowing all devices to speak with one another. The IoT enables the monitoring and tracking of things, facilitating trolley navigation and direction [13]. There are no standardized IoT architectures among organizations. However, several architectures have been presented by various experts [14].

All IoT applications require at least one sensor to collect information from nature [15]. Typically, IoT sensors are small in size, require little work, and use less power. In IoT applications, several types of sensors are employed, including ultrasonic, heartbeat, alcohol, moisture, rain, gas, smoke, color, flex, vibration, and humidity. Our proposed cart utilizes various sensors to gather data that help in decision-making to facilitate the shopping process of visually challenged people. Approximate computing [16] could be utilized where it relies on processing sensory-generated data in an energy-efficient fashion.

IoT components are the hardware and software that comprise an IoT device or system. The four major components of the Internet of Things are [11]: 1) *Sensors and Actuators*: these are devices that gather data from the environment and take actions based on it. They are sometimes referred to as "things" in the Internet of Things. 2) *Connectivity*: The acquired data should be sent to the cloud or another data storage site for processing and analysis. Thus, connection is necessary, which refers to the different technologies that are used to link devices to the internet, such as WiFi, Bluetooth, cellular, or satellite. 3) *Data Processing*: refers to the processes and instruments that are utilized to make sense of the obtained data, and 4) *The User Interface*, which enables humans to engage with IoT devices and systems.

B. Assistive Technology (AT)

Assistive technology refers to all assistive items, as well as the systems and services that support them [6]. Assistive technology aids in the maintenance or improvement of an individual's cognitive, communication, hearing, mobility, self-care, and visual functions, hence promoting health, well-being, inclusion, and engagement. Improving access to assistive technology can help to accomplish sustainable development goals and ensure that no one is left behind. This is accomplished by facilitating the inclusion and engagement of assistive technology users in their families, communities, and all aspects of society, including the political, economic, and social spheres [7].

Wheelchairs, spectacles, prosthetic limbs, white canes, and hearing aids are examples of assistive devices that are utilized for various disabilities. Digital solutions include voice recognition, time management software, and captioning [17]. Most persons who utilize assistive technology use multiple products, making integrated services critical. Globally, around 2.5 billion individuals require one or more assistive goods. With an ageing global population and an increase in noncommunicable illnesses, an estimated 3.5 billion people will require assistive technology by 2050. In many nations, the majority of individuals who use assistive technology lack access to it [18].

Elderly people, children and adults with impairments, and those with chronic health issues such as diabetes, stroke, and dementia require the greatest assistive technology [19]. Assistive technology may assist people in various aspects of their lives, including education, jobs, exercise, leisure, and other daily tasks like self-care, cooking, and reading. Assistive technology may assist individuals, their families, and friends, as well as society as a whole. The WHO and UNICEF global report on assistive technology (2022) reveals significant discrepancies in access to assistive technology. In certain low-income nations, just 3% of individuals have access to the assistive items they require, whereas, in some high-income countries, 90% of people can easily access various assistive technologies. The authors of [6] reviewed the major techniques of assistive technology that have recently been utilized to augment the quality of life of elderly people. The major techniques are community alarms, video monitoring, slide/slip sensors, fitness monitors, hip guardians, pressure rugs, smoke alarms, fire alerts, cooker controls, electronic calendars, door alarms, and motion sensors.

C. Approximate Computing

Approximate computing (AC) has reemerged as a mainstream computing paradigm. The main principle of AC is sacrificing output accuracy and accepting less-than-optimal results to save area, power, and delay [20]. AC is applicable at the software level, e.g., loop perforation, and hardware level, e.g., inexact full adders [21]. Various error-resilient applications, such as machine learning, scientific computing, computer graphics and gaming, and multimedia processing, accept approximation results [22]. Such applications reply to processing big data that are sensory-generated, do not have a unique or golden output, perform computing utilizing self-attenuation algorithms, and most of their results are consumed by human vision which tolerates errors [23].

Approximate computing can be a useful strategy in IoT-based assistive shopping trolleys for visually impaired people to optimize resource utilization, minimize energy consumption, and increase real-time processing capabilities. Here's how to use approximation computing in such a system:

- *Sensor Data Processing*: IoT-based shopping trolleys are outfitted with a variety of sensors, including proximity sensors, weight sensors, and RFID readers, to aid visually impaired customers. Approximate computing techniques can be used to effectively handle sensor data. Instead of analyzing each data point with high accuracy, approximation methods can be used to estimate sensor readings, resulting in less computing overhead [24].

- *Machine Learning Models*: These models are frequently used for item detection and navigation in assistive devices. Approximate computing can be used to minimize computational complexity during model training and deployment. Quantization, pruning, and low-rank approximation are all techniques for simplifying neural networks, making them more suited for deployment on resource-constrained IoT devices [25].

- *Navigation and Path Planning*: To navigate visually impaired customers around a store, assistive shopping trolleys frequently require real-time navigation and path planning [26]. Approximate computing techniques can accelerate these computations while compromising some precision. For example, rather than determining the ideal path using sophisticated algorithms, simpler heuristics or approximation methods can be used to discover a relatively decent solution in less time.

- *Voice and Speech Recognition*: Voice-based interfaces are critical for communicating with assistive devices. Speech recognition algorithms may be optimized using approximate computing approaches, which reduces the computational cost of processing audio input in real-time [22]. Techniques like eliminating less critical characteristics or utilizing simpler models can assist achieve quicker reaction times without significantly reducing accuracy.

- *Energy Efficiency*: IoT devices frequently use limited battery power, making energy efficiency a crucial problem. AC aims for energy reduction by sacrificing computation accuracy. For example, rather than continuously gathering sensor data at high frequencies, approximation algorithms can dynamically adjust sample rates based on the data's value to the job [27].

- *User Feedback and Adaptation*: Assistive systems utilize approximation computing to react to user preferences and feedback. The system may tailor its replies and suggestions by assessing user behaviour and preferences utilizing previous encounters, eradicating the need for substantial processing resources [28].

- *Fault Tolerance*: AC enhances the failure tolerance of IoT-enabled assistive devices. Tolerating errors and inaccuracies in computations allows the system to run reliably even during hardware collapses or environmental disturbances [29].

Incorporating AC approaches into IoT-based Assistive Shopping Trolleys for Visually Challenged People will enhance their performance, efficiency, and reliability while decreasing resource and energy consumption. However, it is important to carefully balance the trade-offs between accuracy and efficiency to ensure that the system satisfies the unique demands and requirements of visually impaired users.

3. Literature Review

The authors of [30] suggested a technique for guiding visually impaired individuals in indoor locations such as retail malls, hospitals, and markets. It requires expensive equipment installed in areas of interest, such as wide-band sensors, a file to store geographical data about the places, a server, a WiFi connection, and a phone. A deep neural network is used to locate the user inside a vast facility. The user initiates the software with a voice command. Because the application utilizes remote resources (the cloud), an active Internet connection is necessary.

An enriched white cane is presented in [31] as part of a micro-navigation system prototype that assists visually impaired people in moving around interior surroundings. The technology recognizes a person's position and determines their speed and direction of travel. Then, the technique calculates the user's trajectory, identifies potential impediments along the way, and provides guidance instructions to the user. The design comprises an enhanced white cane with infrared LEDs, two infrared cameras, a smartphone, and a computer running a software program. However, it is not portable. The authors of [32] presented an application to assist the blind in securely navigating interior places such as schools, libraries, and retail malls, with four major divisions: navigation, barrier detection, destination detection, and voice command units. The approach relies on computer vision and image processing which demand significant CPU resources.

The authors of [33] suggested a technique that uses a YOLO CNN to recognize, follow, and determine fixed and moving barriers faced during outdoor navigation. YOLO identifies automobiles, bicycles, and humans, but it only detects telephone poles, fences, staircases, and garbage cans as entities. The approach demands a recent-generation smartphone, a laptop with a high-performance video card, wireless headphones, and an Internet connection. As a disadvantage, the approach does not supply an alternate route to avoid the highlighted barriers. In [34], a wearable navigation assistance device for blind and visually impaired individuals was suggested. The device has four ultrasonic sensors at eye level, three on a pair of spectacles, and one on the right wrist, as well as an Arduino and a Beagle Bone Blackboard. Sensor-measured spans serve as inputs for a logic fuzzy approach. The design does not provide localization or other guiding functions.

The authors of [35] created a smart shopping tool for visually impaired persons. They want to help visually challenged clients identify items at supermarkets, guide them through all departments, and automate paying. This eliminates the need for users to wait in large queues to charge their purchases. The suggested approach reduces help and offers a welcoming shopping atmosphere for clients. The work of [36] described a full, portable, and cheap smart assistant for assisting vision-impaired persons in navigating inside and outdoors and interacting with their surroundings. The prototype comprises a smart cane and a central unit; contact between the user and the assistant is done via voice messages. The assistant includes GPS, an electronic compass, Wi-Fi, ultrasonic sensors, an optical sensor, and an RFID reader to aid the user in navigating securely.

To make shopping easier, the authors of [37] proposed a smart shopping bag that uses IoT. The consumer carrying the bag will hear a message shown on a Liquid Crystal Display (LCD). After completing the purchasing procedure, the buyer will scan the bag rather than scanning each product individually. Finally, they can pay their bills using mobile phones that have been integrated with the Global System for Mobile Communication (GSM) module or manually. To lower the average waiting time when shopping at the supermarket, the authors of [38] presented an Internet of Things (IoT)-based smart shopping cart made up of Radio Frequency Identification (RFID) sensors, an Arduino microcontroller, a Bluetooth module, and a mobile application. During the shopping process, information is wirelessly transmitted to the server, where invoicing is automatically generated.

The authors of [39] introduced a straightforward audio-based tool that sought to support visually impaired individuals in the simple activity of inspecting whether the light in a room is on or off. It is an illustration of potential low-tech devices that can be developed without the need for detailed skills or knowledge by the user, and that function in a practical way. The work contributed to the ambient intelligence field by indicating how an auditory-based mechanism can be utilized to help blind people check the lights independently and simply. Also, they proposed seven possible pieces of advice for developing assistive technology tools and everyday devices, based on information gathered from a survey.

The authors of [40] presented the requirements of smart cities to improve the mobility and quality of life of visually impaired people. Future smart cities should support smartness in homes, transportation, shopping, healthcare, and social interactions. Thus, visually challenged people would be able to perform indoor and outdoor activities which are motivated by having a disabled-friendly environment. A prototype of an assistive mobile information robot was presented in [41]. The prototype has voice and gesture-based interfaces with Russian speech and sign language recognition and synthesis techniques and a high degree of robot autonomy. The goal of the prototype is to be used as a robotic cart for shopping in grocery stores and supermarkets.

A survey on assistive technology for visually impaired people, who form one-sixth of the world population according to the WHO, was presented in [42]. Various efforts developed several devices that are either heavy or costly. The devices are wearable and handheld with different design characteristics, e.g., weight, price, power consumption, and ease of use. Future research in this direction would be guided by having an efficient algorithm to guarantee independence, mobility, and safety for visually impaired persons.

As we noticed, there is a plethora of existing work related to the shopping cart for visually challenged people. However, they have some difficulties related to high cost, requiring special sensors or special training to handle, requiring significant CPU resources, using a smartphone which already depends on visual inspection, and the need for some training. Our concept differs from related work in that it contains a thorough shopping cart integration with all required features, such as real-time pricing information. Furthermore, there is no need to use a separate shopping cart and stick. The smart cart serves two functions: it facilitates movement and transportation, and its dedicated track keeps it at an ideal distance from items and departments, further increasing mobility. Compared to other designs, our designed cart is simple in addition to its reduced cost. Moreover, it is easy to add more sensors and features due to its modularity. The incorporated features are the basic ones required by the shopper. Thus, it encourages supermarkets and shopping malls to use it.

4. System Architecture and Implementation

In markets and shopping malls, multiple types of trolleys are utilized in various forms such as transferable grocery carts, baby strollers, and standard shopping carts. The proposed cart has various modifications compared to the standard cart. Proposing a system that delivers a decent quality of life for visually impaired persons is a challenging research issue because it is critical to create solutions that enable persons with vision impairments to engage in social activities so that they feel included. Combining many features in a single cart will result in a revolutionary device that might revolutionize the face of shopping for the visually impaired.

The schematic diagram of the suggested cart is demonstrated in Figure1. The system includes two main components, i.e., hardware and software, as explained below.

A. Hardware Components

Ultrasonic Sensor: It recognizes the presence of items at certain distances surrounding the smart cart, as seen in Figure 2. The sensing range is 40 cm to 300 cm, with reaction times ranging from 50 to 200 milliseconds. The

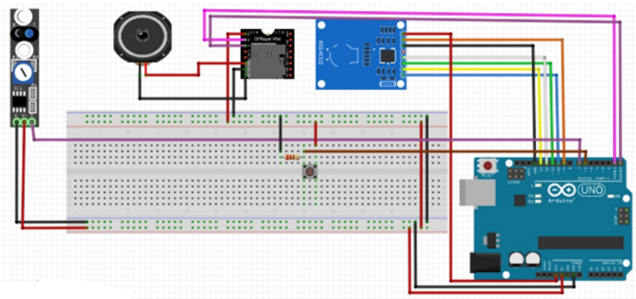

Figure 1. The Schematic Diagram of the Smart Cart

sensor has an accuracy of ±5% and can work from 20 VDC to 30 VDC. The ultrasonic wave has a frequency of 120 kHz, and the voltage at the sensor output ranges from 0 to 10 VDC. Its ambient temperature ranges from -25C to +70C. The sensor costs around 5 JD.

Figure 2. Ultrasonic Sensor

Infrared (IR) Sensor: This module has a built-in IR transmitter and IR receiver that transmits out infrared light and examines for echoed infrared rays to catch the existence of any barrier in front of the sensor as depicted in Figure 3. The functional voltage is 5VDC, and the I/O pins are 5V and 3.3V compliant. It has an adaptable sensing coverage with a built-in ambient light sensor. The supply current is 20mA, and the average cost of the sensor is 5 JD.

Figure 3. Infrared (IR) Sensor

Arduino Uno: It is used to control and manage all electronic devices of the project. It is based on an ATmega328P Microcontroller with 5V Operating Voltage as shown in Figure 4. The limit of the input voltage is 6-20V and the recommended input voltage is 7-12V. It has 14 digital I/O pins, six of which provide pulse width modulation (PWM) output. It contains six analog input pins. It has 32 KB of flash memory (ATmega328P), 0.5 KB of which is utilized by the bootloader. It weighs about 25 grams and costs roughly 25 JD.

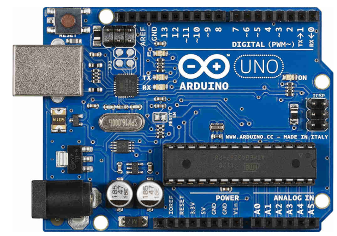

Figure 4. Arduino Uno

Radio-Frequency Identification (RFID) Sensor: It is a technology that uses radio waves to wirelessly transmit data between a reader and an RFID tag attached to an object, typically for identification, tracking, and management of the object as shown in Figure 5. Its working voltage is 5V DC and its frequency 125KHz. The read range is up to 3 cm with a maximum data transfer rate of 10 Mbit/s. It costs around 10 JD.

Figure 5. RFID (Radio Frequency Identification) Sensor

Push Button Switch: As shown in Figure 6, a push button is a momentary switch commonly used to control electronic devices, where pressing the button completes an electrical circuit, triggering an action or function, and releasing it interrupts the circuit. The mode of operation is tactile feedback and the power rating is a maximum of 50mA with 24V DC. The operating temperature of the button is -20C to +70C.

Figure 6. Push Button Switch

Hardware Integration: An Infrared (IR) sensor is a device that notices infrared radiation. In the context of

Arduino, IR sensors are commonly used for various applications, such as detecting the motion of an object, proximity sensing, and remote control systems. RFID sensors are commonly used with Arduino for various applications, including access control systems, inventory management, and identification purposes. Ultrasonic sensors are frequently utilized with Arduino in distance-measuring applications. They work by creating ultrasonic radiation and then analyzing how long they require for the sound waves to return after impacting an object.

Arduino Uno is a μcontroller board, that encloses the on-board power supply, a USB port to communicate with the PC, and an Atmel μcontroller chip. It simplifies the operation of building any control design by delivering a programmable classic board that can be attached to the system without any complex PCB design and fabrication. It is open-source hardware, where the details of its design are available to anyone who can alter it or produce his own himself.

B. Software Component

Arduino IDE: Integrated Development Environment is a software application used for writing, compiling, and uploading code to Arduino boards. It provides a user-friendly interface for both beginners and experienced developers to program Arduino microcontrollers. The percentage of visually challenged people in Jordan is 11.1%, and accordingly, this project was created to give them the traditional shopping experience without the need for facilitators.

The experimental concept for the proposed system uses RFID technology to distinguish each section and individual products put on the shelf. The shopping cart includes an RFID reader, RF recipient, microcontroller, Arduino UNO, and Secure Digital (SD) card. Each shelf is labeled with an RFID tag that marks the item on it. RF transmitters are installed at the start of each section to convey the portion's identifier to the receiver when they are within range.

RFID employs radio waves for recognizing labels attached to goods. Tags are classified as either active or passive. An active tag has a built-in battery and may send the signal again. Passive tags store data that has been digitally maintained. The device comprises an antenna, an embedded chip, and a means for receiving DC power from the reader. In our design, we use passive tags since they are less expensive and can be stretched to cover a bigger area of the business. Figure 5 depicts passive tags with an operating frequency of 125 kHz.

RFID scanners identify the tag's distinctive code and alert the Arduino, which then talks with it. The RFID Scanner unit has a reading range of up to 10 cm. It checks and powers the tag so that it may transmit the 12-bit unique recognizing code. The reader's antenna receives the signal. The RF transceiver is used for sending and receiving massive amounts of data. RF modules are tiny in size, with a range of voltages for operation of 3–12V and a bandwidth of 433MHz. These transceivers may transmit data in the form of strings or integers. Both the transmitter and the receiver are connected to the Arduino. Our endeavour requires that they submit the section name and pricing of each item.

The shopping place should be equipped to accommodate visually challenged people by placing guiding lines on the floor to navigate through different sections. Additionally, adding tags on products for identification, including information about the products and their prices, would be beneficial.

RFID was used instead of a barcode reader because it is less expensive and easier to deal with, provided that there is an RFID card or RFID Mifare Keychain affixed to the products instead of a barcode. If the project idea is implemented on the ground, the form is replaced with appropriate alternatives. In our project, the idea of a one-directional road was adopted so that it could pass through all departments.

C. Supportive Infrastructure

The successful implementation of smart shopping carts and full user testing for visually challenged people requires the availability of supportive infrastructure, including:

- *Wireless communication*: Reliable wireless connections, including Wi-Fi or Bluetooth, are required for communication with Mall's appliances.
- *Accessible retail structure*: There should be large aisles and clear paths throughout the mall. To facilitate simple navigation, appropriate signage has to be installed.
- *Training and support*: The mall employees should be knowledgeable about the technology being utilized and competent to offer the necessary assistance.
- *Instruments and guidance technology*: As more sensors are employed, the user can access additional capabilities. The more costly it would be, though.
- *Mobile Application Integration*: Using a mobile application in conjunction with the smart cart would be advantageous for maximum benefits. Voice-based services like routing, product seeking, cart tracking, and aisle direction should be available with such an application.
- *Maintenance and technical support*: To guarantee correct and long-term operation, the smart shopping cart has to have regular maintenance. Therefore, it's necessary to do routine maintenance and replace any damaged parts or sensors.
- *Data Security and Privacy*: The smart cart's requirement to gather user data and personal information includes the usage of mobile applications. Therefore, following the applicable data protection rules, appro-

priate privacy and data security precautions should be implemented.

- *Feedback system*: To make shopping for visually impaired persons more enjoyable, a feedback system should be in place where they may voice their opinions about the carts and other amenities that are given.

All this infrastructure should be provided by the shopping mall since it requires financial investment and early integration.

D. System Scalability and Adaptability

A smart shopping cart that is both scalable and adaptive for individuals with visual impairments requires careful consideration of both technology aspects and user experience. This involves taking the subsequent actions:

- *Requirements gathering and user research*: The first stage involves doing an in-depth study to understand the needs and obstacles faced by those with visual impairments while they shop. Thus, essential requirements and preferences are gathered from possible consumers.

- *Define Key characteristics*: The goal of user research is to determine the key characteristics of the smart cart, such as the ability to recognize products using RFID, speak commands, provide audio feedback when an impediment is detected, work with other assistive technologies, and integrate with mobile devices.

- *Scalable Architectures for Hardware and Software*: The implemented architecture needs to be modular to facilitate the addition of new parts. Moreover, easily replaceable design elements are necessary to provide scalable design.

- *Data Privacy and Security*: The mobile application and shopping cart should securely and appropriately protect sensitive user data. Therefore, it is imperative to incorporate security measures and rigorous data privacy.

- *Continuous iteration and improvement*: Real-time data is gathered on shopping cart performance and customer input. Next, make use of the data gathered to enhance the cart's design, keeping in mind the addition of new features to guarantee the design's scalability and flexibility.

- *Seamless integration with existing systems*: The suggested and designed cart ought to function with the Wi-Fi network and mobile applications that are now installed in the shopping centers.

These criteria will help us design a smart shopping cart that can effectively serve visually impaired individuals and evolve to meet changing user needs and technical improvements. We also prioritize user needs, accessibility, and scalability.

5. System Evaluation

We have developed a prototype of a smart cart designed to assist individuals with visual challenges. The cart is equipped with various sensors to facilitate navigation and product identification without the need for external assistance. In particular, we used *infrared* sensors to identify different sections and help the shopper walk on a predetermined path, *ultrasonic* sensors to detect nearby objects/obstacles and provide alerts through the speaker, and *RFID* sensors to identify products and announce their prices via the speaker system.

Figure 7 shows the top view of the designed smart cart while Figure 8 shows the front view of the cart. The shopping mall provides carts for the customers, and the successful implementation of the proposed cart depends on introducing some modifications to the shelves that hold the items. For example, at the beginning of each section, an infrared sensor will detect the smart cart and inform the user about his current location, i.e., the section he just entered. Figure 9 shows a horizontal line that represents the track that the cart should follow without deviating left or right. The figure shows three sections where the cart user will hear an audio message containing information about each section as his cart passes the black line.

Figure 7. Top View of the Smart Cart

As shown in Figure 10, the visually challenged individual will initially enter the store and receive information about the name of each section through a headset as he

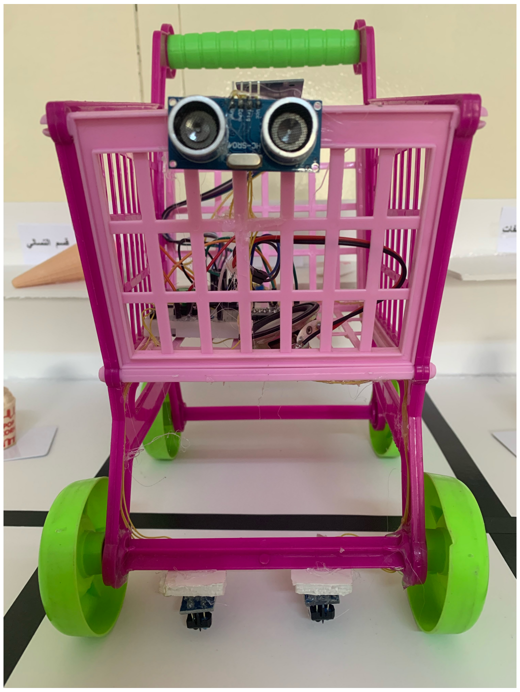

Figure 8. The Front View of the Smart Cart

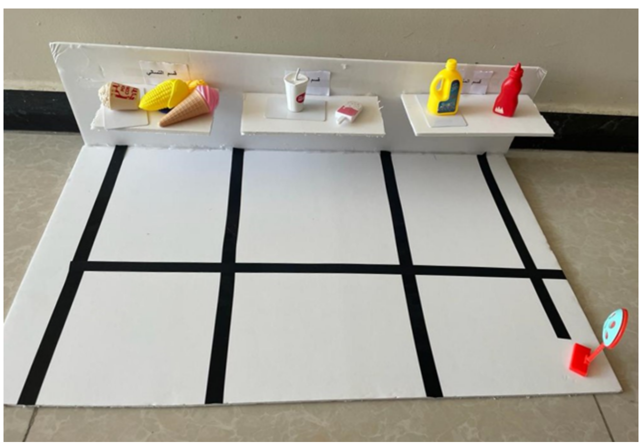

Figure 9. A Prototype of the Store Modified to Facilitate the Usage of the Smart Cart

approaches it. After selecting an item from the shelves and scanning its tag, the headset will provide the shopper with information about the selected item so he can decide if he will purchase that item. The information includes the name of the product, manufacturer/company name, its price, its main ingredients, expiration date, nutrition facts, some advice for cooking, and any other information written on the package of the product.

While shopping, when the cart user deviates from the correct path as shown in Figure 11, he will be alerted through the headset to adjust his path in the desired direction. When the cart user finishes the shopping process and reaches the store's exit as shown in Figure 12, he will be informed of this. He can press an emergency button installed on the cart to let the staff know when he needs assistance.

Figure 10. Entering the Store and Crossing the First Shelf

The suggested cart demonstrated strong obstacle recognition capabilities, promoting safe passage through congested aisles and around obstructions in the retail setting. Furthermore, the system's AC methods demonstrated efficient task execution for items like path planning and item recognition by efficiently balancing computational accuracy with resource usage. Figure 13 summarizes the main steps of the shopping process. As indicated previously, the cart user will hear a message when he enters and exits the shopping area. Also, we will receive a warning message when he deviates from the line, while a message indicating the name of each sector is given based on the location of the shopper and his cart.

We designed a smart shopping cart for visually challenged people. It can offer several improvements, enhancing their shopping experience and promoting independence:

- *Obstacle Detection*: Smart shopping carts can have detectors to detect obstacles in the shopping area. This helps prevent collisions and ensures a safer

Figure 11. The Cart Deviates from the Correct Path

Figure 12. Existing the Store and Crossing the Last Shelf

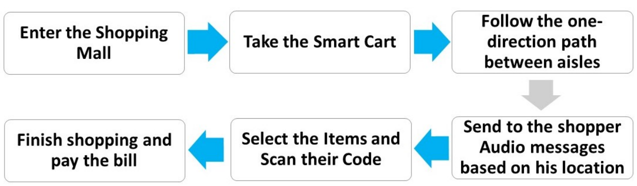

Figure 13. The Flow Chart for the Shopping Process

shopping experience.

- *Voice Commands*: Users may use voice commands to ask the shopping cart about product information, and the cart can deliver audio feedback in real time.
- *Emergency Assistance*: In case of emergencies or unexpected situations, the cart could have a built-in emergency button to call for assistance.

Both system developers and visually impaired users can benefit from the assistive shopping trolley's design's use of AC methods. AC allows for large reductions in computing complexity and energy consumption, even at the cost of minimal accuracy loss in non-critical computations. This extends the operating lifespan of the assistive device and improves user satisfaction. Additionally, resilience against temporary mistakes is ensured by the intrinsic fault-tolerance of AC-based systems, which adds to the overall reliability of assistive technology.

It is essential to recognize the trade-offs that come with approximate computing, especially for applications that are crucial to safety, like assistive devices. AC can improve performance and efficiency, but it can also bring errors or uncertainties that could endanger user safety or usefulness. To ensure that approximate computing techniques fit the rigid criteria of the desired application area, great thought must be paid to their selection and validation.

All things considered, the Approximate Computing-based Assistive Shopping Trolley is a promising development in assistive technology that shows how AC approaches may be used to help visually impaired people with their everyday problems. These technologies have the potential to empower individuals with improved independence, accessibility, and quality of life via ongoing research and innovation.

6. Conclusion and Future Work

Designing, developing, and deploying a smart shopping cart for visually impaired persons taught essential lessons about inclusive design and technical innovation. This project emphasizes the necessity of using technology, including approximate computing and IoT, to meet the individual requirements of various user groups, hence increasing accessibility in routine activities such as grocery shopping.

The work prioritizes user-centric design, including audible feedback, easy navigation, and seamless integration into existing buying procedures. Furthermore, it emphasizes the potential of technology to bridge barriers and empower people with disabilities, e.g., visual challenges, as well as the beneficial influence that inclusive solutions may have on overall quality of life. The approximate computing-based smart shopping cart is a poignant reminder of how careful, accessible design can help to create a more inclusive and equal society. The designed cart is cheap and easy to use, and the assistive device is embedded within the shopping cart.

To further improve performance while preserving acceptable levels of accuracy, future research areas may concentrate on improving the AC algorithms used in the assisted shopping trolley. This may be accomplished by utilizing machine learning and optimization approaches. We aim to improve the design such that various carts can communicate with each other. Also, replace the RFID with a barcode reader and add a navigation system to facilitate access to some products. Also, the system would save information about previous visits and utilize it in future visits. Furthermore, the system's usefulness might be expanded by working to incorporate more sensory modalities and sophisticated navigation algorithms. This would allow the system to perform seamlessly in a variety of retail locations and meet the changing demands of those who are visually impaired.

7. Acknowledgment

The authors would like to thank the Deanship of Scientific Research and Graduate Studies at Yarmouk University for their financial support.

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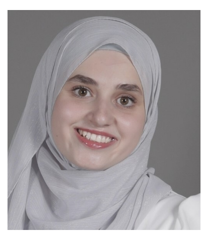

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