Assisting Visually Impaired People using Autonomous Navigation System and Computer Vision for Grocery Shopping

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***Abstract*— Visually impaired people face lots of challenges when doing daily tasks like grocery shopping. Hence, a grocery shopping navigation assistant that covers the shopping preparation, the route creation, the navigation through the store and the product identification has been designed. In this paper we present the design flow of a novel system using the Internet of Things (IoT) and Computer Vision (CV) to assist people with visual impairment (PVI) for grocery shopping. The system starts with assisting the user creating his shopping list using the personal smart phone and Speech-to-Text (STT). Then, the system accesses the database of grocery store to optimizes the route for locating the items in the shopping list with minimal time and effort. Once the route is created and the user is in the store, the smart phone physical navigation system starts using landmarks – QR codes – and using Text-to-Speech (TTS) for guidance. When the user is correctly placed, the product recognition starts and TTS is used to fetch the product.**

Keywords— People with visual impairment, mobile application, optimization, computer vision, code detector and barcode detector.

I. Introduction

World is facing a problem related to the vision health of its population. Nowadays, according to the World Health Organization WHO, approximately 2.2 billion people has been diagnosed with a visual impairment or blindness [1], and the figure is expected to continue increasing with time, in particular, it is expected that the global blindness triple by 2050 [2]. Therefore, the quantity of organizations bringing the traditional assistance to people with visual impairment (PVI) has been rising too. New lines of investigation have also been opened, and different novel technologies are being designed and tested to assist the PVI providing them with a higher level of independence for their daily tasks.

People with visual impairment face many challenges on their daily basis. Simple tasks such as grocery shopping, catching the bus or finding an office on campus pose extra difficulty [3]. Some research studies, such as [4], [5], [6] or [7] , have documented the difficulties encountered by the blind when shopping. The authors of [4] concluded that the most difficult tasks for the subjects of the experiments were discrimination between packages and navigation through the store to specific product locations. On [5] the authors evaluated the importance of certain information for visually impaired people when doing their groceries. The results were that information related with the price, the type of product or the location of a desired item was highly important for them. Also, this research showed that almost half of the participants preferred to be given that information by sound.

In order to solve the challenges visually impaired people face when shopping, several authors have developed systems for them to navigate through the store and identify products from the shelves. Particularly, some of these projects have been focused on shopping in grocery stores. For example, the authors of [8] implemented a product identification and navigation system by using a hand device with a camera. The authors of [5] developed an application for the users to introduce their shopping lists, built a smart cart for the user to navigate through the store and avoid obstacles, and implemented Radio-frequency Identification (RFID) technology in the cart to obtain information about the products. On the other hand, in the project developed in [9] the author focused on creating a mobile application capable of guiding the user through the aisles as well as helping him/her to locate the products.

Other projects have focused only on the identification task. For example, the authors of [10] developed a grocery shopping assistant that identified products using RFID tags and communicated the result to the user using a phone device, Bluetooth and Text-to- Speech (TTS) technology. AiSee creators developed in [11] an identification system capable of reading labels using Computer Vision and Artificial Intelligence using a headset prototype with cameras. The authors of [12] implemented a product recognition system based on smart glasses and object recognition algorithms. Also, commercial applications to identify products can be found, like Taptapsee that, as shown in [5], is already widely used by visually impaired people to obtain information of their environment using their cellphone's camera.

However, mostly all the mentioned systems are systems that only cover the navigation or/and identification processes. As explained in [13], the developed systems for visually impaired people to do their groceries can be classified in:

- Shopping preparation systems
- Navigation and product identifications systems

When reviewing the current state of the art of grocery assistant systems for visually impaired people, projects were found in one or the other category, but no system covering both the shopping preparation process and the instore navigation and product identification was found. Therefore, the aim of this project has been to develop a system that not only focuses on one of the categories but in both, assisting the user from the creation of the shopping list to the checkout at the store.

II. System Design

The designed system has been a grocery shopping assistant for visually impaired people that covered the entire shopping process. The goal was to not only solve the problems that visually impaired people faced when they were in the store, but to provide a system where they could introduce their desired products at home and that would create a personalized route for them to do their groceries later in the store.

The system can be divided in four different subsystems, which have been developed and implemented separately to be later integrated.

- *Subsystem I: Shopping List Application.* This subsystem consists of an application for the user to introduce his/her shopping list. It features Text-to-Speech and Speech-to-Text to communicate with the user.

- *Subsystem II: Route Optimization Algorithm.* After the shopping list creation, this subsystem obtains the shortest path for the user to get the desired items in the store. It uses information about the inventory of the store and the products' location. The algorithm is solved as a Travel Salesman Problem (TSP). The route consists in different checkpoints corresponding in the specific locations of the products of the user's shopping list.

- *Subsystem III: Store Navigation.* Once the user has introduced his/her shopping list in the application and the optimized route has been calculated, the system waits for the user to go to the store. When the user arrives to the store, the store navigation subsystem is in charge of guiding the user through the aisles, following the optimized route, going from checkpoint to checkpoint. This is done by using landmarks consisting of QR codes and a camera and voice instructions through TTS.

- *Subsystem III: Item Recognition.* Once the user is located in a checkpoint, he/she needs to grab the corresponding item. In this subsystem, computer vision is used to recognize the item and check if it is the correct one as well as giving voice instructions with TTS. The items are recognized by their barcodes.

Apart of the mentioned subsystems, the designed grocery shopping assistant includes a database in charge of storing all the information related to the system. A diagram of the system is shown in Figure 1.

III. Implementation

A. Database

As aforementioned, the project has used a database to store all the information created and used by the subsystems, especially the data that is relevant for several of them. It is a SQL database, and it has been deployed using a Raspberry Pi as its server. It is called "Grocery Assistant" and consists of 6 tables, which have been listed below.

- *Shopping list.* This table is created by the user when creating the shopping list in the application. It consists of a table that contains the product and the quantity wanted as well as the id of the list or the user identification.
- *Inventory.* It is provided by the store and stores information about the products of the store and their location like the product name, the stock, the ID of the product, the location of the product within the store (aisle, shelf, orientation) and the location of the item in the shelf (height respect to the ground, position).
- *Checkpoints.* The checkpoints table is provided by the store and stores information about the store layout in terms of checkpoints. The aisles and shelves are transformed into checkpoints and the neighbors of this checkpoints are also stored for the computation of the route afterwards.

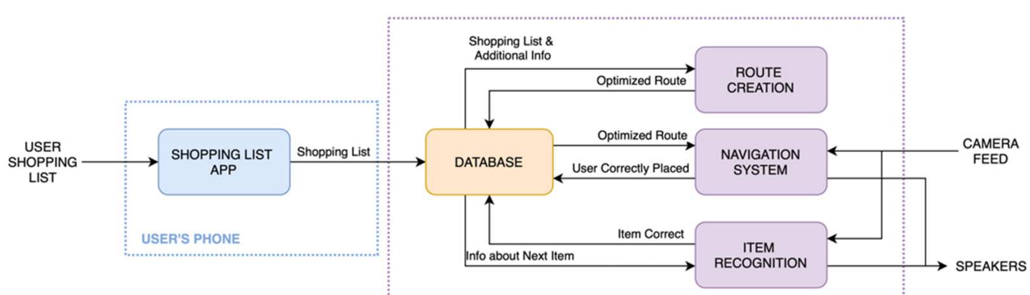

Fig. 1: Grocery Assistant System Design Flow Diagram

- *Store_map.* It is provided by the system and allows to know the distance, the path, and the directions for all the checkpoints combination possible that is used to calculate the path and to indicate if there are any obstacles in the way.
- *Route.* The Route is the result of the computation of the optimal route so the items are stored in the order the user must take them. It gives information of the checkpoint and orientation the product wanted is placed at, as well as the location of the product in the shelf or the quantity of the product required. This table is handled by the number of order which is an index to know the order the products must be picked
- *Status.* The functionality of the system is divided into three subsystems so, in order to enable the communication of these subsystems, as well as to keep track of the status of the user in the shopping process, the Status table was created. It contains information about item the user is looking for in the route, if he is correctly placed, the last checkpoint the user has visited or the id of the list he is using.

The following table gives a clear vision of the operations that each agent of the system is allowed to do with the database.

TABLE I: System's agents' permission into the database depending on the table

Table of Database	**Components of the System**		
	Raspberry Pi	***User***	***Store***
Checkpoints	Read	-----	Create
Inventory	Read	-----	Create-Update
Store Map	Create	-----	-----
Route	Create -Update	-----	-----
Status	Update	-----	-----
Shopping list	Read	Create-Update	-----

B. Subsystems

Subsystem I has been developed as an Android application using AppInventor. The application has two different screens: user's screen and product's screen. The user's screen allows the user to select his/her user ID. The product's screen is the one where the user can add or delete products from his/her shopping list. All of the buttons deployed in the application have a Text-to-Speech function associated to them. Therefore, when they are pressed the application prompts via voice the text written on the buttons. The flow diagrams of both screens are shown in Figure 3. As it can be observed, the application is connected with the SQL database deployed in the Raspberry Pi, modifying the shopping list table.

Subsystem II has been deployed as a python script in the same Raspberry Pi acting as the database server. As aforementioned, it is in charge of creating the optimized route based on the items introduced in the shopping list. The designed system follows the flow diagram displayed on Figure 4. As it can be observed, the information of the shopping list is extracted and processed. Then, the items are looked up in the inventory table, to get the aisle and shelf location of each of them. The route is created based on all the items that have to be collected by the user in his/her next visit to the store. The problem is solved as a naive TSP algorithm, and the result is stored in the route table of the database.

Subsystem III starts when the user accesses the store or he/she just have located the wanted item so he must go to the next checkpoint as seen in the work flow of Figure 2. Then the video feed starts and in case it detects a non-repeated QR, it reads the information of the aisle and the shelf and converts it into the corresponding checkpoint. This checkpoint is compared with the checkpoint of the next item in the route, and if it does not match, the navigation instructions start. To know which instruction give the user, the initial checkpoint, this is where the user is now located at, and the destination checkpoint, this is the checkpoint where the product is located, are used to obtain the optimal path from the store map table created by the system. This path contains the list of checkpoints to be followed, where the next checkpoint to visit is retrieved and used to select the proper voice instruction. In case the user is located in the destination checkpoint, the orientation is checked and in case of not being the one wanted, the system would inform him to rotate to face the right orientation and would start the process again until the orientation read and the wanted one matches. When there is match in the orientation, then the system proceeds to inform the user that he is now correctly placed as well as informing him where the product is in the shelf he is facing. This implied the update of the user status variable of correctly placed to true.

Subsystem IV starts when the status of the user states that he is correctly placed initializing the video feed. Then, the system would wait 15 seconds to detect a new barcode, and if it is not detected, it informs the user to turn around the product to scan other area of the product. When a non-repeated barcode is detected, it is read and compared to the item ID of the product wanted for the checkpoint the user is located at. In case the product is not the required one, the system will give him returning instructions and, in case of a barcode matching, the system informs that the product is correct and it will tell the quantity required. The flow diagram of this subsystem is shown in Figure 5.

C. Integration and Deployment

All the subsystems were developed and tested separately before continuing with the integration and the final deployment of the system. The process of deployment and integration implied other tasks like importing all the python files to the Raspberry Pi or the installation of the needed libraries with possible compatibility problems. It also includes the connection with the programs in charge of the route computation or the app. It made clear the need to create of a ‘head’ program that allows managing the different programs and regulates their execution based on the status. As the management is based on the status instead of the time, it implies an asynchronous management. The solution adopted is the use of subprocesses.

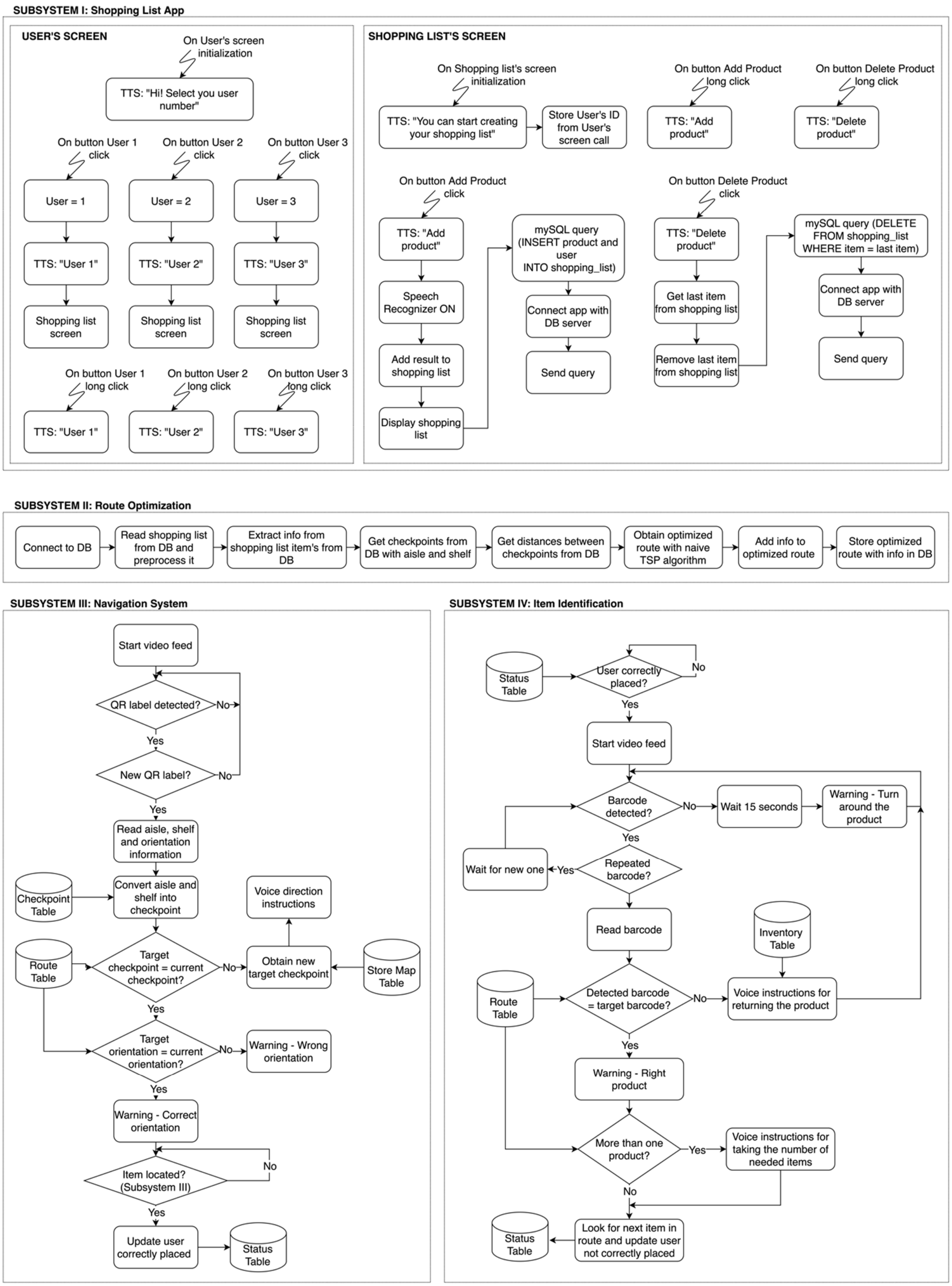

Fig. 2: Flowchart of the Subsystems of the Grocery Shopping Assistant

Subprocesses are tasks that a python script delegates to the Operative System (OS) and don't need installation for using them as they are in a built-in library in Python named subprocess. The program which runs a subprocess would be paused until the subprocess is finished, in other words, if a program calls two subprocesses, the second one wouldn't start until the first one has finished as the execution is sequential.

Once this concept was clear, the next step was creating the main program to run the different subsystems based on subprocesses. Besides the initial configuration that was done at the beginning of the subsystems like the generation of the QR codes or the obtention of the custom instruction was merged into one script for the initial set up. The initialization of the parameters is executed once the user is in the store and the guiding starts.

In terms of integration, the prototype used is the combination of the Raspberry Pi, a power bank, a camera and a speaker.

IV. Results and Discussion

To appreciate the results of the system, a demo was prepared where a shop was simulated creating the corresponding tables. In the chosen case, the store has two aisles and two shelves making a total of 11 points with two orientations each where the checkpoint number 6 corresponds to check out. The QR codes were generated and sticked to the shelves according to the layout presented below in Figure 3.

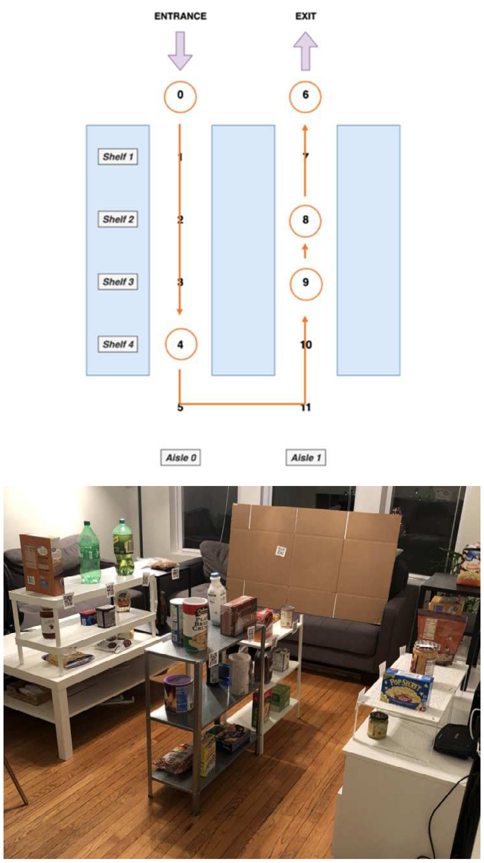

Fig. 3. Grocery Store Simulation Environment for Navigation and Product Fetch

When the set up of the store was in place, a shopping list with three elements was created for user two. With the list created the main program is running and detects that the new list has been added, the list is preprocessed, and the route is computed being the result the points 4, 9, 8 ,6.

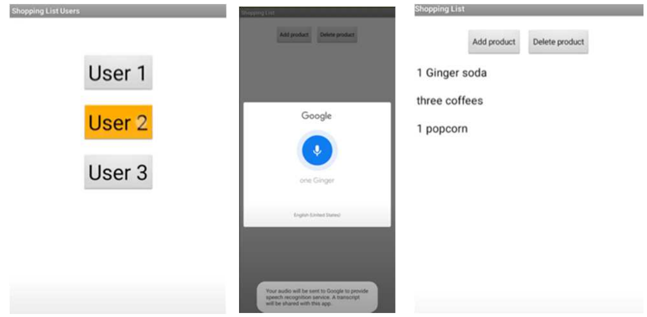

Fig. 4. Shopping list mobile application

Then, as the main program workflow diagram states, the navigation starts based on the recognition of QR codes. The navigation starts guiding to checkpoint 4, as it is the first checkpoint in the route table.

Fig. 5: QR label (left) and barcode (right) reading

The testing of system was successful, and it led to different possible feature lines.

- Self-driven cart to guide the user around the store. It will ease the guiding as the cart will be in charge of the navigation and will help the user to follow the route with less complications.
- Creation of a web page for the store end to optimize the creation of the inventory and the checkpoints autonomously. It has been considered that the store entries its layout directly but it would be interesting to implement a program that, using Artificial intelligence, could generate the checkpoint layout to ease the work for the store.
- The deployment of the system in a mobile phone. In this project a Raspberry Pi is used but it would be interesting to see how all the system is deployed in a mobile phone to reduce the number of items the user needs. This couldn't be done in this project as the personal phone was an iPhone which has the ability of running Python OS scripts diminished and the availability of the test phone was limited.
- Implement an anxiety control to track the stress level of the user. As mentioned in the state of the art, one of the most stressful situations for the user is grocery shopping so it would be curious to track the user signals using IoT, in

particular the heart rate variability as it is a natural stress indicator, and adapt the instructions to this parameter.

- Generate custom recommendations or set nutritional score. Storing and using the last shopping carts of the users to make personal recommendations and make the user spend less time while doing it. Besides, the nutritional score of the aliments could be analyzed to make him custom recommendations based on the diet he is following.
- Use of an intelligent shopping cart within the store. Nowadays, there is a bunch of stores which have intelligent shopping carts. It would be the substitute of the Raspberry Pi and it would be in charge of the navigation too.

This system could be used in other scopes like warehousing to control and manage them and their inventory. This would allow the company or warehouse to track all the products following the optimal route and see if there is any missing item or if it is something wrong with the merchandise.

V. CONCLUSION

After reviewing the current situation of PVI doing their groceries, a grocery shopping assistant was chosen as the topic for this project. Several projects can be found in this field, but there is a lack of a system that successfully covers the whole shopping process. Therefore, with this project, people with visual impairment will gain more independence as they will be able to buy their groceries without any external help.

In this document, the system that is developed and implemented has been described in detail. The system consists of three subsystems, which starts from the shopping preparation before going to the store to the check-out of the products. The grocery assistant will help PVI to navigate through the store using CV, optimizing their route according to their shopping list, and to identify their desired items with CV too. It is important to mention that even though this system has been designed for PVI, it could be used by any type of user.

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