Bilkent University

Department of Computer Engineering

Senior Design Project

Project short-name: GroceryBee

Group number: T2323

Project Specifications Report

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1. Introduction

Online grocery shopping has been offered by numerous markets for years now, however especially with the advent of the COVID virus and the following quarantine period, there has been a considerable surge in the number of online grocery orders. Specifically, Turkey's online market grew by 434% and reached $244.9 million in the first half of 2020 [1], during the time when COVID first became a part of our lives. The supermarket chain "Migros" was already offering an online shopping option, and with the popularity of online grocery shopping booming, new companies have also started investing in online grocery shopping options for their platforms, such as Morhipo and Trendyol. It was reported that the growth in fast delivery startups, such as Getir and Banabi, exceeded 50% and the provinces Migros delivers to have gone from 58 to practically all provinces in Turkey. During the pandemic, the demand for virtual markets almost quadrupled [1]. In the US, 70% of shoppers stated they would be buying groceries online by 2022, and Walmart's US ecommerce sales grew by 79% in the third quarter of 2020. It is estimated that e-commerce warehouses will be fully automated by the year 2029 [2].

It is apparent from the aforementioned information that demand for online grocery shopping has skyrocketed in the past couple of years, and investing in this field is surely a worthwhile engagement. To this end, we will be developing a robot, named "GroceryBee", to automate and expedite the task of gathering grocery items from the shelves of supermarkets for online orders. GroceryBee is a robot designed to assist grocery stores in keeping up with their online orders. GroceryBee will help grocery store employees by collecting the items which are required for an online order from the store shelves, thus speeding up the delivery process. Additionally, GroceryBee will restock shelves which are empty and keep updated stock information in order to inform customers on whether a product is available in the store or not. Consequently, supermarket employees will have received an assist in their jobs, and they will be able to work simultaneously with GroceryBee to serve customers. There are similar projects for accomplishing tasks akin to what we are trying to achieve. However, GroceryBee will not only safely and accurately gather grocery items, but it will at the same time help grocery store employees with keeping the markets in order. Moreover, although there are robots which are engineered to accomplish tasks such as managing inventory or notifying employees about shelves that need to be restocked [3], none of these robots are designed to do all of these, and even more, altogether, unlike GroceryBee.

In the following parts of this report, first the description of our project will be briefly given. Afterwards, project constraints will be explained in detail and professional and ethical issues related to our project will be discussed. Following this, the requirements, both functional and non-functional, will be defined. Finally, an explanation of risks involved in our project and our priorities, as well as ideas for future spin offs will be given.

1.1 Description

For the automation and acceleration of gathering grocery items from the shelves of supermarkets for online orders, we will be developing our robot “Grocery Bee”. For this, we aim to leverage theories from different fields in science and engineering. GroceryBee will have to make decisions in an uncertain environment, and in this uncertainty it is not possible to plan everything precisely beforehand, therefore our robot will exploit the real-time information from its camera (both RGB and depth) to make real-time decisions and changes in planning (a robot might see a person blocking its path, and change its path to the destination etc.). For perception, connectivist approaches which have achieved state-of-the-art results will be employed. Therefore, neural models will be used and perhaps trained according to our purposes; both for the detection of the product to be handled and for sequential decision making. For example, the robot might have to analyse the situation of the item and check if it is stuck, or has other items around it. Deep learning approaches will pave the way for the robot to assess the situation and segment the item of interest from a window of frames. Different architectures have been shown to achieve SOTA results (such as transformers) in generative and understanding tasks regarding computer vision. Robot actuators and grippers apply control theory in motion/trajectory planning and as mentioned above to leverage the sequential information gathered from the feedback system. This is important for the robot to execute sequential decision making and be responsive to its environment. We will also use simulations (Drake) that use control theoretic design and analysis to enhance the robustness of the physics engine. Open problems in motion planning, perception, decision making will be worked on using these approaches from various disciplines.

There are already robots out there even though they are not really common, but we will attack problems regarding sequential decision making, motion planning, perception etc. to improve the current developments in robots. Therefore, we may categorise our work as **sustained innovation**. For the **optimization** of the task of gathering grocery items from shelves, we propose the **transformation** from the current system (i.e. actual people doing the task) to an autonomous process. As mentioned, even though this proposal exists, we aim to create market value for our product by growing and enhancing the existing approaches and solving problems that occur in different fields which make the robot not very usable. Innovations we will make are expected to affect the internal processes (in a market setting, in our case) and create improvements in costs of hiring people, but also pave the way for the organisations (supermarkets) to provide their customers with a faster, better service. Consequently, our robot emphasises the **process type of innovation** framework, as it aims to enhance the inner processes of a market.

1.2 Constraints

Implementation

- The robot will be developed using Drake—a simulation toolbox developed at MIT Computer Science and Artificial Intelligence Lab (CSAIL) that enables model-based design and verification for robotics. The perception of the robot will be built in Drake.
- Python will be the main language for developing the robotic skills, through Drake's Python integration.
- OpenGL API will be used to render 2D and 3D vector graphics.
- MeshCat will be used to remotely run and view 3D simulations on the web.
- For computer vision, learning will be enabled by the PyTorch framework while the Open3D library will be used to facilitate geometric queries.
- Libraries such as IPOPT, SNOPT, Gurobi, and MOSEK will be utilised as optimizers.

Cost

- Building a physical robot or buying a premade one would cost well over the budget of this project, and are out of the project's main focus. The robot will only be built virtually through simulations since the gap between simulation and reality is neglectable in robotics nowadays.
- The Drake simulator and other libraries and APIs are free to use.

Design

- The robot cannot be too wide in order to fit in between the shelves in the supermarkets.
- The robot must be able to move between shelves without the need for external support.

Health and Safety

- The robot should avoid any kind of collision, especially with humans, for the safety of the customers and employees around.
- The robot cannot carry out sudden, unexpected maneuvers since that would threaten the individuals nearby.

- The robot will not have pointy, sharp edges or parts made of harmful materials that may cause harm when in touch with human skin.

Sustainability

- The energy consumption of the robots will be reduced by optimizing the paths the robots will take [4].
- The use of unsustainable materials in the production of the robot will be avoided, with the exception of sensors, computer chips, etc. [5], [6].
- For sustainable development, no prototypes or physical components will be built. All testing and development will be carried out through virtual simulations.

Time

- The reports and demos as part of the course CS-491 will be prepared and handed in before the deadlines stated in the course requirements.
- The robot will be virtually implemented before the project delivery deadline and ready to be showcased at CSFair in Spring 2023.

Language

- The robot will only recognize item names in English.
- The shopping list will be provided only in English.

1.3 Professional and Ethical Issues

- Any and all libraries, frameworks and tools used in GroceryBee should be licensed properly.
- The orders given to the robot should be securely stored to ensure the privacy of all customers.
- Regardless of the security of the system, the users should be notified that their data is being processed in GroceryBee.
- The project might result in an amount of lost jobs, but this might get fixed by the fact that GroceryBee might start new job areas of its own.
- The project is proprietary for now, however it might be open source in the future.
- The data processing should be compliant with data protection laws such as GDPR.

2. Requirements

2.1 Functional Requirements

System Requirements

- GroceryBee should be able to collect required items in response to the orders.
- GroceryBee should be able to navigate in the supermarket aisles without crashing.
- GroceryBee should have access to locations of products within aisles and navigate to the location when an order is requested.
- GroceryBee should be able to detect the requested object in the shelf from the camera frames, identify relative 3D coordinates, use the gripper to pick up the object safely and bring the object to the delivery point without damaging the item.
- GroceryBee should be able to calculate the most optimum path for requests with multiple items and collect them accordingly.
- GroceryBee should inform the employees about stock information and alert if stock is low when it arrives on the shelf.
- GroceryBee should be able to restock the shelves in the supermarket.
- GroceryBee should be simulated in a simulation rather than a physical robot.

2.2 Non-Functional Requirements

Usability

The application should require only the information of the items such as the images, names and locations. GroceryBee should be able to collect the requested items and bring it to the delivery point within the supermarket.

Efficiency

When multiple items are requested in the same order, GroceryBee should calculate the shortest path and collect the orders to save time, energy and money.

When GroceryBee arrives at the aisle to collect the item, it should calculate the most optimum way for its arm to move to grab the item.

Extensibility

GroceryBee should be designed so it could be operated in environments with multiple robots which could communicate with each other. In the future if a system with multiple robots is introduced, the GroceryBee should easily be converted to a multi-robot application.

In the future, it could work in environments that have humans.

Reliability

GroceryBee should collect, carry and deliver items without damaging them. When an order is requested, GroceryBee should ensure successful delivery.

Data should be processed securely to ensure that it is protected and not leaked to third parties.

3. Risks

Time may not be estimated perfectly, or in other words, time allocated for learning the robotics tools may exceed the schedule and leave less space for the implementation of the project. Therefore, the project has its priorities set in terms of functionalities, which will be mentioned in the next section.

The aspects of the project (i.e. perception algorithms, simulation technologies) that are initially considered to be premade by others and therefore neglected in the task allocation may in fact require extra work and time to be built. These concerns will be clarified as we learn the necessary tools like Drake, and the support provided by them.

Wrong or unrealistic estimations of what a robot can achieve within the boundaries of modern technology and tools available to us are also one of the risks that may leave some of the features hanging. For instance, we have observed from our competitors that modern robotics technology doesn't allow robots to function at high speeds, especially when they have to navigate in an unstructured environment and perform actions. Therefore, we cannot expect our robot to be extremely swift at collecting items from the shelves.

4. Priority Planning & Future Spinoffs

The primary function of GroceryBee, which will be our main concern, will be to collect the items for online orders by walking through supermarket aisles in an optimized manner and

correctly identifying required products, after which it will carefully pick them up from the shelves, put them in its basket and deliver the items to the correct spot in the supermarket.

An extension of the project might be to turn it into a multi-robot system, where multiple Bees in the same environment interact with each other and the task allocation is done collectively. This will require the pathfinding algorithms to be enhanced by accounting for multiple agents and optimizing the total outcome. Moreover, the robots will have to avoid any collision with each other while working together. This is an interesting aspect to work on but might be annulled due to time constraints.

We have also considered a human interaction aspect for the robot, where it would inform customers and employees on whether an item is still in stock, and if it is, where it could be found. However, considering the complexity of this task, we may not implement this function initially as part of the senior design project, and it will remain as an idea for a possible extension of the functions of GroceryBee in the future.

Additionally, GroceryBee could even be extended in the future to assist more of the daily supermarket tasks like detecting spillages on store floors and cleaning them while navigating through the store to ensure the cleanliness of the supermarket. Nevertheless, it is not brought into the project's aims since it is far from the project's main focus of the collection of ordered items, and it will require much more resources and time to implement.

5. Design and Implementation Timeline

Below is the intended plan that will be followed during the development of GroceryBee.

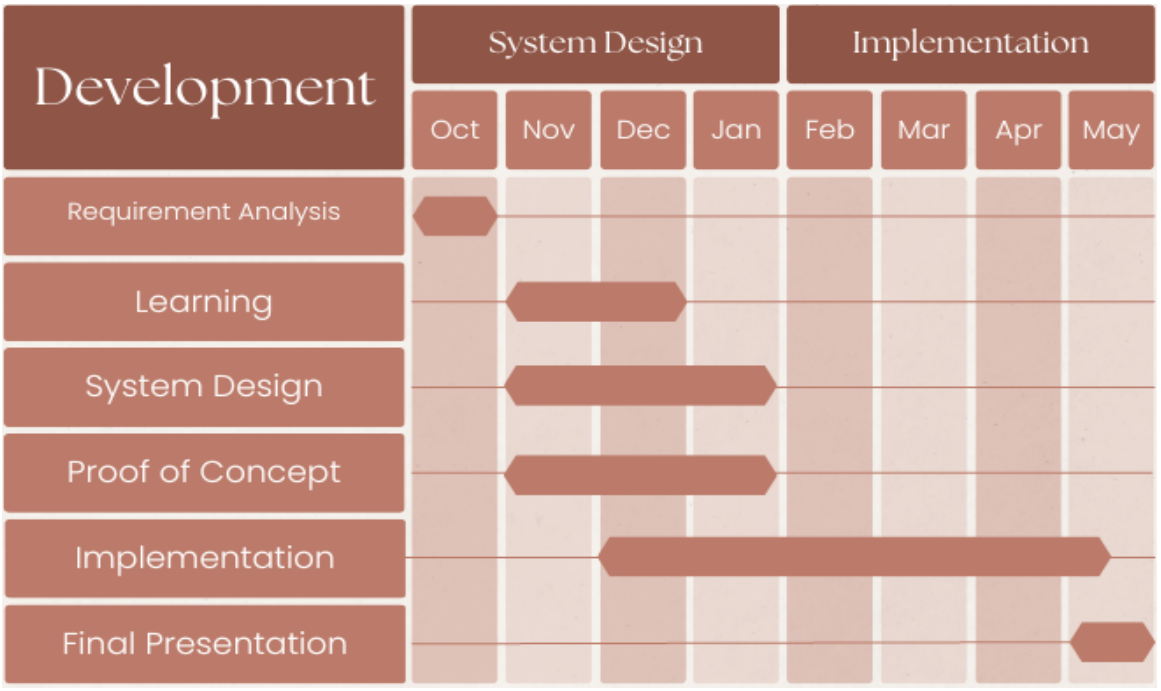

Figure 1: GroceryBee Development Gantt Chart

References

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