November 20, 2011

Dr. Andrew Rawicz
School of Engineering Science
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Burnaby, BC
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Re: ENSC 305 Design Specification for an Office Automated Delivery Robot

Dear Dr. Rawicz,

Attached document contains design specifications for KAEFI's Office Automated Delivery Robot system. Our system will provide convenience in office spaces while securely delivering important documents and other packages from one cubicle to another. This is possible by having lockable compartments with software controlling them. An application installed on PC will offer easy-to-use User Interface which will be used to put in query for the delivery. QR barcodes embedded on the floor will be scanned by the robot for localization of itself. A path-finding algorithm will be developed to find its way through the office spaces.

Our design specification encompasses the prototype's software and hardware modules. It will not assure the final design of the project. However, the ideal form factor and functionalities will be revealed in this document.

KAEFI is composed of five senior engineering students with experiences through numerous Co-op(s) in the industry and research projects. We strongly believe that our product will not only be educational but competitive and beneficial, we are Gyu Han David Choi (CEO), Jin Sun Ahn (CTO), Hongbae Sam Park (CFO), Kyu Seo Lee (CMO), and Yongho Choi (COO). Should you have any question about our system, attached functional specifications, please contact us by email at kaefi-support@sfu.ca

Sincerely,

Gyu Han David Choi

KAEFI, Chief Executive Officer

Design Specification

For the Office Automated Delivery Robot

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Rev 2.1

Executive Summary

KAEFI's OADR, short for Office Automated Delivery Robot, under the marketing moniker of QRunner, will aid workers manage their time more efficiently by actively partaking their workload. With our robot, the office workers will not have to leave their stations to make deliveries of objects such as office documents, supplies, prototype devices, and most important of all, coffee. We believe as a result, the workers will be able to focus on their task better and the productivity of the office will see an increase. Companies by nature thrive to increase efficiency of their operations and such efforts have been translated to their needs to unman and automate office spaces. Recently, a lot of interest has been casted on robots that are aimed to be used in office spaces; more and more companies are jumping into this newly created office robot market. Two examples of current commercially available office robots would be the PR2 robot, commissioned by Willow Garage in California, US, and the QB, built by Anybots also in California, US [1]. Both are in a different league when speaking of target market, compared to our OADR; the former is a $400,000 machinery equipped with state-of-art intelligence, cognitive ability and versatility using its two arms. The latter is a robot designed to simply facilitate tele-presence, such as video conferences. The aforementioned two robotsshows commercially viable robots have been advancing toward the office market. The OADR is our shot at this rapidly expanding market, and the OADR can be applied to any office seeking an inter-office delivery solution at a low cost.

Our OADRwill consist of mainly adsPIC33F seriesmicrocontroller, two DC motors, a proximity sensor, a camera, power supply, and the laptop. These devices will be integrated to form a single operational system which consists of software programming and additional hardware and mechanical components. The attached document contains detailed design specifications explaining the design of the OADR. This document will summarize every design specifications from gear material and electrical components to software requirements. The two major development stages for which the design specifications shall be addressed are the following:

Software Development	-	QR Decoding, Motor Control, Server/Client Network, Database, Path finding Algorithm, User Interface, and System Integration
Hardware Development	-	Robot Chassis Development, Propulsion Mechanism, Collision Detection, and Storage Compartment Operation

Throughout the project the KAEFI development team will refer to the design specifications to ensure that all the design requirements are met. This document will serve as aresourcewhichour software and hardware engineers will frequently visit to achieve our goal.This design specifications document has been written in compliance with laws, bylaws, codes and acts that govern North America's consumer product standards.

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Glossary

Microcontroller	The "brain" of the robot. Provides centralized processing capability
OADR	Office Automated Delivery Robot
PC	Personal Computer
PWM	Pulse Width Modulation. Method of controlling motor
QR	Quick Response. A type of barcode that can store information in a two-dimensional graphical form
Server-Client	A model of computer network
Wi-Fi	A mechanism for wirelessly connecting electronic devices

1. Introduction

The Office Automated Delivery Robot (OADR) is an office robot that will deliver packages and documentsin primarily office spaces. Office workers and personals can request a delivery or a pick-up on a dedicated webpage at their will in the comfort of their own stations. Then, the robot will come to their stations to either pick up the desired object to be delivered or drop off the object. The idea is that workers do not have to make deliveries themselves, and by doing so, we hope to aid workers that are overloaded by work and do not have time to move around the office, so that they can better focus on their own works. As a result, it will save time and increase work efficiency in the office. Our OADR system is composed of many different parts – of which the functional specifications were discussed in the previous document. In this document however, the design specificationsof our OADR robot that illustrate the technical detailsof each part and how the design specifications were chosen to meet their corresponding functional specifications will be discussed in the proceeding topics.

1.1 Scope

This document will describe the OADR and how all of the design aspects of the robot system references toward the functional specification for the OADR[9]. Moreover, it will discuss specific components and explain the intension of its design. Ultimately this document will serve as an outline which can be referred back to ensure desired designs meet or exceed the specifications.

1.2 Intended Audience

This document is primarily intended to be used internally by the members of KAEFI. The members of the KAEFI shall use this document as a guideline during the course of the development. Also, external audiences such as project supervisors, legal consultants, and standard organizations shall use this document in the events such as certification of the proposed robot system or there may arise any legal issues.

2. System Specification

The OADR will deliver the packages to designated destination according to the queries that have been sent from the users to the database system. The OADR will monitor its status and compute the route when the users submit requests for a delivery. The users will be able to request the delivery with its destination through the computer connected to the Wi-Fi network. When the location of the user and the destination of the delivery are sent to the database, the OADR retrieves that information to calculate the shortest path and controls the motor via microcontroller. While the OADR is moving, it detects obstacles using proximity sensors and scans QR code on its path to update its location. Upon arrival at the destination, the OADR will open its storage door for the recipient to pick up the packages.

3. Overall System Design

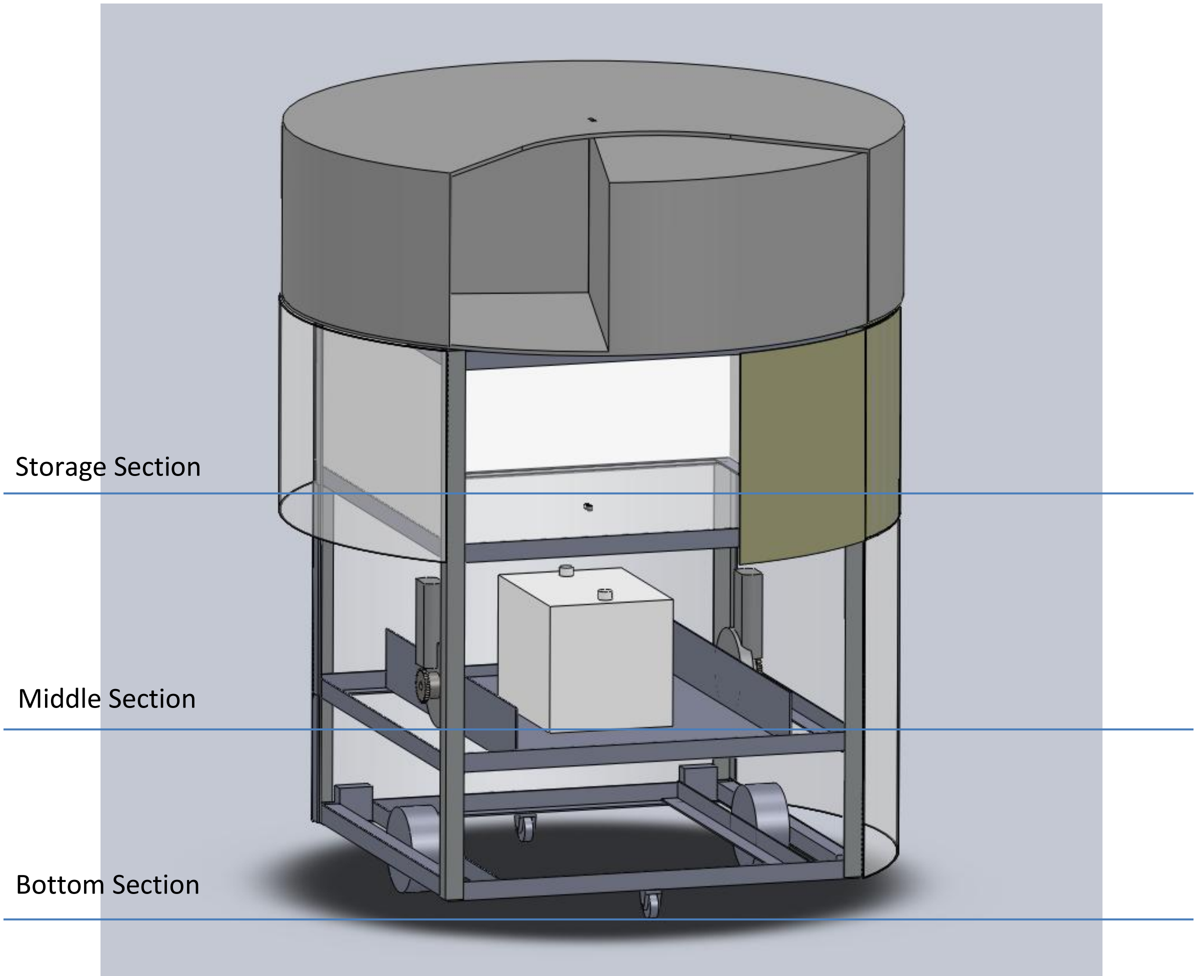

Figure 1: Graphical Representation of the OADR Structure

3.1 Mechanical Design

The OADR can be divided into three major sections. The topmost section is the storage section, which is composed of a secured rotating compartment on top and a larger stationary compartment with a motorized sliding door on the bottom. The middle section is the control section, where battery, microcontroller, motor, and other vital components are located. The bottom section is the propulsion and QR detection section, where drive wheels, caster wheels, and a camera are located. In order to satisfy one of the functional requirements that the OADR must be as light as possible, we chose aluminum as the main building material in constructing the robot chassis.

3.2 Electrical System

The entire system will be powered from an automotive deep-cycle battery. The automotive battery was chosen because it can store a large amount of energy (high Watt-Hour) and high current (up to 15 Amps) that is necessary in driving the DC motors.

3.3 Consideration

3.3.1 Noise Consideration

Because the OADR has motors, gears, and the controllers inside of the OADR's body that may generate a large noise, handling noise is of particular concern in our design. To minimize the noise that is generated from the mechanical parts, the following steps will be taken in our design.

- Sound-proofing materials will be used inside the OADR's body where mechanical parts are placed
- Carefully laying out the mechanical parts

3.3.2 Safety Consideration

To protect users from getting harmed from events such as an electrical shock or contact of appendages with moving mechanical components, following steps will be taken:

- Major electrical and mechanical components such as battery terminals, wires, gears, and motors will be placed inside of the OADR and covered with protective covering as much as possible
- Body part of the OADR will not be easily accessible by users, maintenance will be done by trained technicians

3.4 Power Supply

Our power supply requirements are:

- Maximum Current: 20 Amps
- Voltage: 12-14 Volts
- The battery temperature shall not exceed 50°C at all conditions
- Current Regulated

The voltage and current requirements are crucial for the reliable operation of the DC motors. The OADR will be powered from an automotive deep cycle battery. One of the main reasons that we have chosen this battery is because it can provide a steady amount of large current over a long period of time (High Watt-Hour). The temperature on the external part of the battery shall not exceed 50°C to prevent thermal damages on nearby components as well as the user. The battery may have a built-in current regulator or an external regulator may be used to output a steady stream of current. The current shall be regulated to prevent ripples which may affect motor speed.

3.5 Software System

Software design of the OADR will be implemented with the following components:

- Database and website
- Path Finding Algorithm
- Camera and QR decoder
- Motor Controller with DSPIC 33FJ64MC802

Database is designed with MySQL and controlled through a PHP website (UI) to manage the query of the requests and the status of the OADR. It will be communicated via the infrastructure network between the user and the OADR.

Once the delivery request has been acknowledged to the OADR, finding the shortest path between the delivery point and the destination has to be determined and calculated. Our shortest path finding algorithm will be based on the 2-D vector computation. The positions of the QR code will be pre-determined manually, so that the path can be calculated in advance.

As the query fills up with a request, the camera mounted on the OADR will be executed to capture the image for the QR code scan. The camera will constantly capture image in every 0.5 seconds to detect the QR code in the captured image. Once the QR code is detected, it will go through the QR decoder phase to parse and decode the information from the QR code.

To control the physical movement of the OADR, reliable motor control software is essential with microcontroller to control the wheel. For the microcontroller, a dsPIC33FJ64MC802 microcontroller from Microchip will be used.

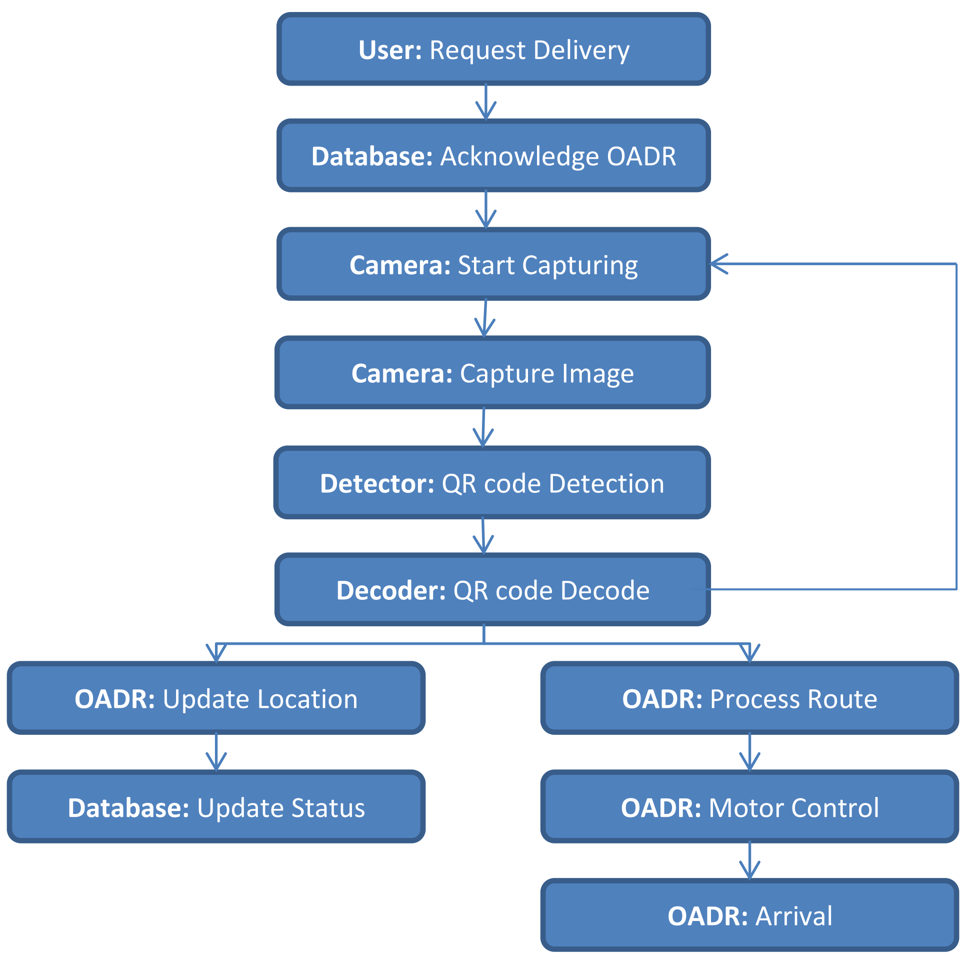

Figure 2: Software Design Flow Chart

4. The OADR Bottom Design

The lower section of the OADR includes the drive-train as well as the camera. The drive-train will be a crucial component of the OADR providing accurate movement and stability. A camera will be used to scan the QR code placed on the floor to update the location of the OADR.

4.1 Physical and Mechanical Design

The placement of the wheels will determine the location of the camera. While the camera requires sufficient room for capturing the QR code beneath the OADR, the drive-train components have to consume the least possible space in the lower section.

4.2 Wheel Specification

Two 4” heavy duty rubber wheels are used as the main driving mechanism. These wheels have ½” bearings and 19-teeth sprocket for chain linkage to the driving motor. A stainless-steel axle with the same diameter is used. Four shaft collars are used to hold the wheel on the axle. Custom made wheel mounts secure the wheels to the robot frame. The wheel mounts are made of composite wood material to achieve strength and lightness. The wheels are attached to the side of the robot as shown in Figure 4. Only two driving wheels are implemented to reduce the complexity of the project. A set of caster wheels are mounted on the front and the rear of the robot for stability.

4.3 Camera Specification

Camera will be mounted on the beneath the second platform (the middle section) to scan for the QR code on the floor. The camera will be mounted in such way that it is easy to adjust the distance between the floor and the camera to achieve the optimum field of view and focus. As the user instructs the delivery, the camera will be turned on to capture the image every 0.5 second. When there is no more query on the database, the camera will be shut off.

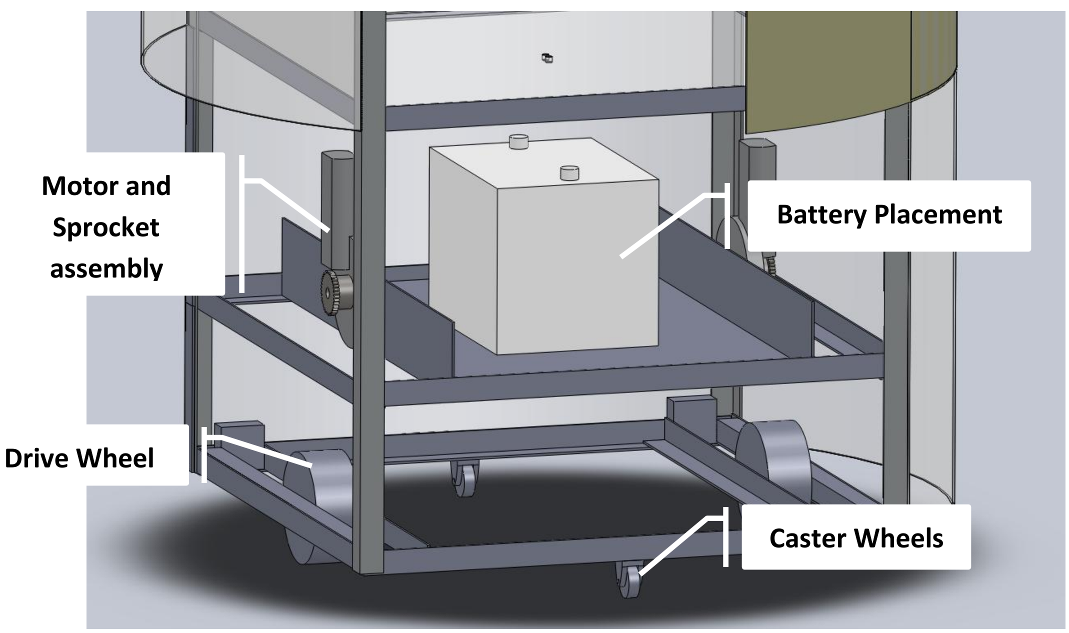

Figure 3: Close-up of the Bottom Section

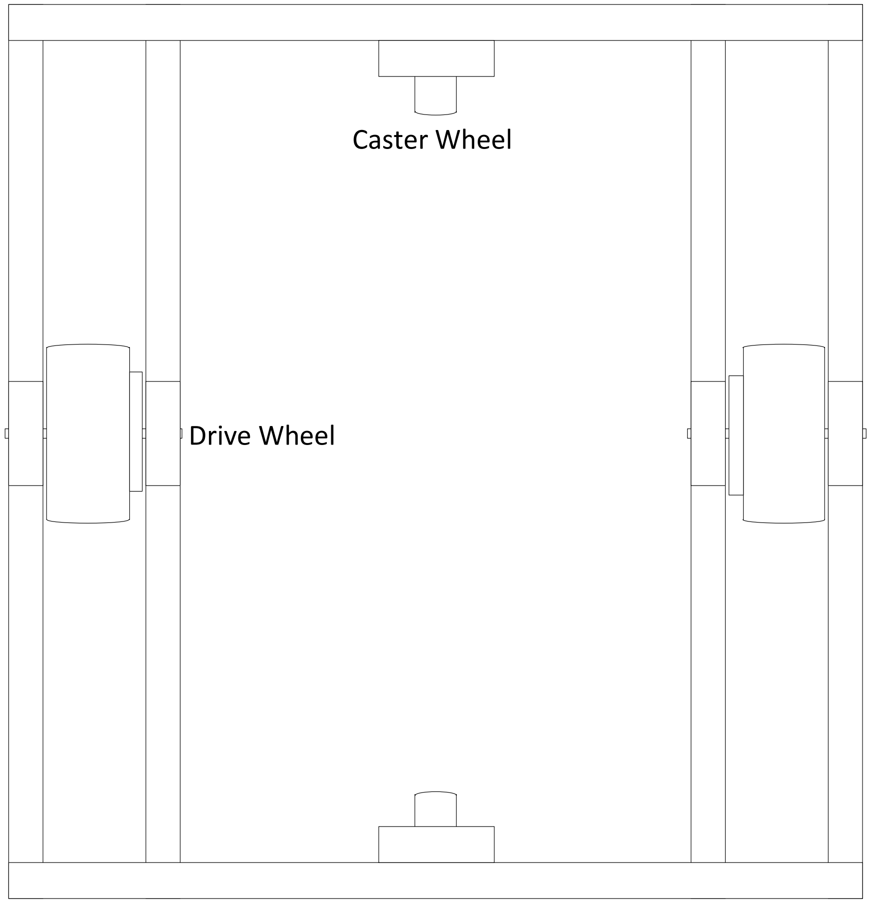

Figure 4: Wheel Placements from Top View

5. The OADR Body Design

5.1 Physical and Mechanical Design

The two drive wheels are driven by two AME-214 series motors from AMEquipment. The motors are frequently used in automotive windshield wiper systems for their high torque output, and the torque numbers (up to 15Nm at23 Amps) are adequate for our application. The motors are permanently attached to a worm gear gearbox which reduces the max speed to around 70 rpm (revolutions per minute), while providing plenty of torque (16Nm at stall) for our application. We've devised a very simple physical model to represent the static and dynamic behaviour of the OADR while it is in operation. Our experiment dictates that the worst-case friction coefficient between the robot and the various flooring materials in the Applied Science Building is about 1.3. Therefore, since the projected weight of the OADR is in the vicinity of 30kg, the OADR needs upwards of 400N of force to start moving. This translates to roughly 10 Newton-meters of torque is needed from each of the two motors when using 4" wheels.

5.2 Battery

An automotive deep-cycle battery is chosen because of its availability and the ability to provide high current for the DC motors. The battery weighs considerably (around 20lb), hence it will be placed as near to the center of the robot as possible to maintain center of gravity at the center of the robot.

5.3 Motor Placement

A set of two DC brushed motors will be placed directly above the wheels in order to put weight on the wheels for better traction. As well, the placement shall be as low as possible to achieve low center of gravity.

5.4 Motor Control

The two AME-214 series motors are controlled via a dsPIC33 series microcontroller. This series of microcontroller was chosen because of our familiarity with it thus easy to work with, and it has lots of desired on-board features such as a pulse-width-modulation (PWM) generator and an analog-to-digital converter, both of which can be used to form a closed-loop motor control system. For our purposes, a dsPIC33FJ64MC802 microcontroller shall be used. This particular model of microcontroller is compact, does not consume much power, and has 32 pins which is adequate for our purposes, and has two PWM generators, each of which can drive one of the two motors. The microcontroller will be programmed in C language via MPLAB IDE which compiles written codes and programs the microcontroller.

5.5 Gears (Driving Mechanism)

Each of the motor shafts will be attached to a 19-teeth metal sprocket. These sprockets are no. 35 19-teeth stainless steel machined one-piece sprockets from Linn Gear Co. The drive wheels each have a no. 35 19-teeth sprocket readily attached to them. The material that this sprocket is made of is chromoly. Both sprockets – on the motor and on the wheel – are linked by a metal chain. The size of the chain is also no. 35 to accommodate the sprockets. Metal parts are used throughout the drive mechanism to ensure they can withstand the weight of the robot and the torque of the motor.

6. The OADR Top Design

The Top level of the OADR will have a secure storage compartment. Mainly, plywood will be used as a primary material for construction of this module for strength and lightness. The maximum weight that the storage compartment shall be no more than the OADR itself can carry, about 30 pounds.

6.1 Physical and Mechanical Design

The secure storage compartment will have a stationary cover with a section that is opened up. The inner piece is the rotating part and it will be divided into four sections. When one of the four sections is open, other three sections won't be accessible due to the cover. When the OADR retrieves an item from a sender, the software will keep track of which section it was placed in. While moving, that section is obscure. When it reaches the destination, the section with the package will show up for the receiver.

6.2 Motor Placement

A brushed DC motor will be sufficient for rotating the inner section of the secure compartment area. A motor will be placed directly beneath the compartment. A small wheel attached to the motor will contact the compartment and drive it.

6.3 Storage System

The storage module will be constructed using plywood. The choice of material is due to the total weight of the system. We are trying to reduce the weight as much as possible for making an agile prototype. As mentioned above, there will be four sections in the storage compartment and only one of them will be accessible. Other three will be hidden under the stationary cover.

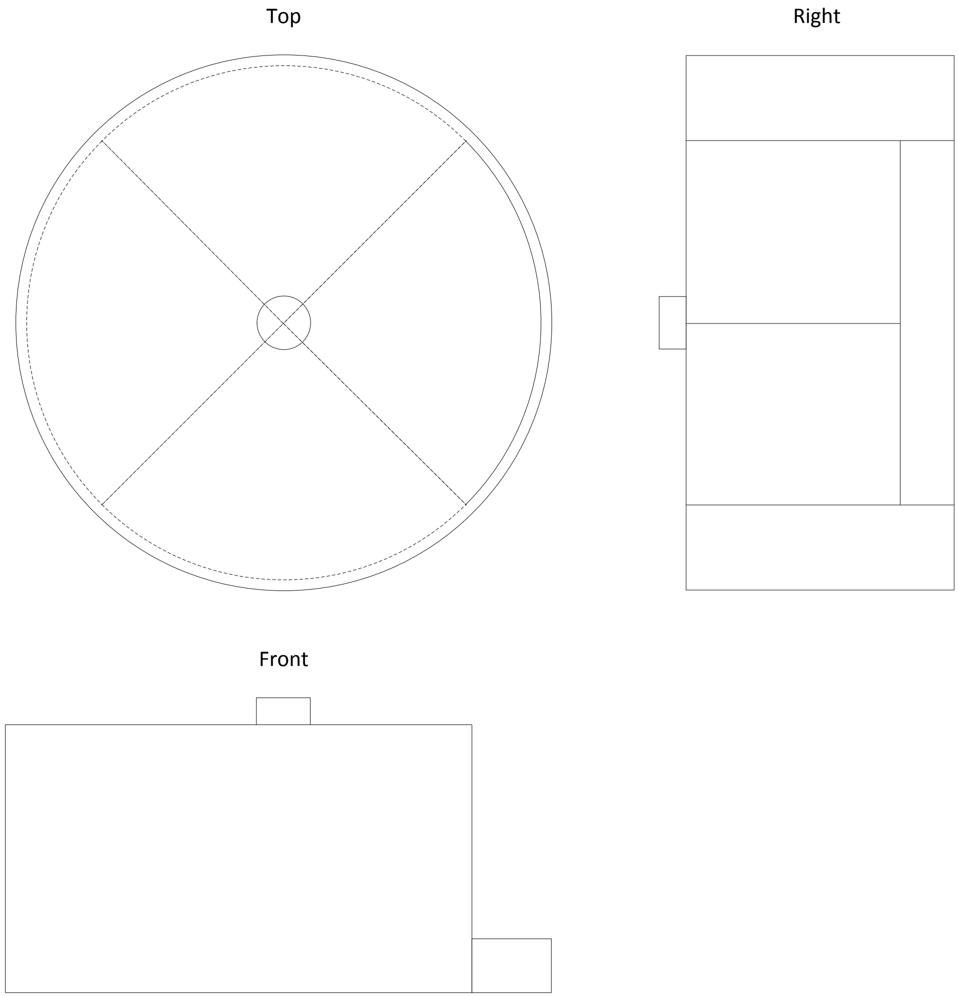

Figure 5: Secure Storage Compartment Design

7. Software Design

7.1 QR Decoding

For simplicity in image processing, we used OpenCV, an open source computer vision library. Using OpenCV, we are able to process images easier for QR decoding.

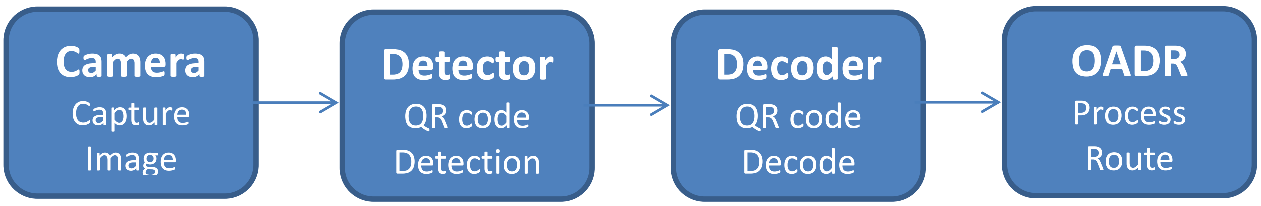

Figure 6: QR Decoding Process

7.1.1 Detector

After OADR is awakened by a user request from the database, the camera is turned on to scan for a QR code. When the camera captures the QR code, it needs to be acknowledged whether it is a QR code that contains valid information of the designated location. To determine whether the captured image contains the QR code, we need to process the image.

Figure 7: QR Code Detection

After the camera sends the image, we scan for the three corners of the QR codes as illustrated in Figure 7. Based on these three points, the size of the QR code is determined for the decoding process.

7.1.2 Decoder

For decoding of the QR code, we will refer to the open source 2-D barcode library implemented from *Zebra Crossing* which allows us to decode the QR code that is detected from the QR detector. As soon as the QR code is detected, the decoder starts to decode the byte array of the data. Then, the decoded data is parsed to ASCII code so that we can recognize what the information that the QR code contains is.

7.2 Path Finding Algorithm

The path finding algorithm used in our system is fairly simple. The starting location of the robot will always will be point "A" which can be also represented as (0, 0). When the robot is requested to go to point "G" or (2, 1), the required move is simply current coordinate subtracted from destination coordinate. In other words, it will be (2, 1) minus (0, 0). This can be translated as move 2 blocks to east and 1 block north. The same methodology can be used from any current position to any destination coordinate. If the calculated value is negatively signed, it simply means that the robot has to move in negative direction (South or West). The algorithm also keeps track of the robot orientation in real time. With this information, the software will correct the robot's direction for correct path finding.

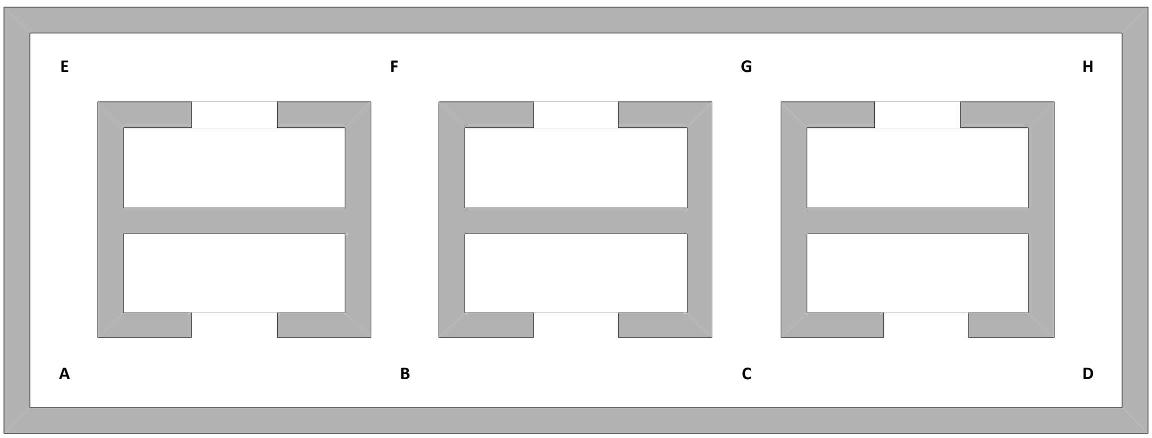

Figure 8: Office Space Path Finding Algorithm Example

7.3 Database

The main purpose of database is to store and select data to the storage. The stored data will give it out the path or current station and the destination of the OADR. The database design is one of the critical because the system keep tracks and takes order from database. Depending on the design of query, the whole system could be dimed. In order to solve this problem, we have designed the appropriate columns and well structured query. The following table is the design of table in database. These following columns will be filled when the OADR takes order or when robot arrived to destination.

Column Name	Column Explanation
ORDER_NUM	Every order will have their unique number
ROBO_ARV	Robot's starting station
ROBO_DES	Robot's destination station
ROBO_STRT_DT	Robot's order time and date
ROBO_PRIORITY	Robot have their own priority of work

Table 1: Database Structure

Depending on the priority column of the table, the OADR could switch direction to other stations that are close to current path.

7.4 Website

The main purpose of the website is for the users to input the starting point and the destination point, so these inputs can be passed to the database and the OADR can retrieve the data from the database. This simple website is made by combinations of PHP and HTML languages. HTML will take care of the design of the website and main actions will be executed by PHP.

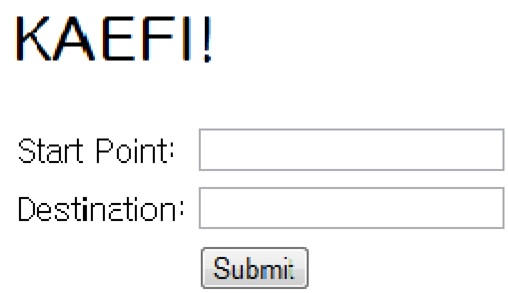

Figure 9: Website UI

8. Sensor Placement

8.1 Proximity Sensor

One or two proximity sensors will be used as a collision avoidance measure. Our choice for proximity sensor is be Devantech's SRF02 ultrasonic range finder, or equivalent. This sensor will be strategically mounted in front of the robot to prevent the OADR from running into obstacles. There are various situations that we have to consider that the robot may run into. There are possibilities that the OADR may collide with people walking around in an office or unexpected items may move into the way of the OADR. In order to counteract these potentially problematic situations, the proximity sensor will detect whether there is an obstacle in its way. If there is an obstacle that the OADR cannot overcome, the OADR will take an action so that whenever objects block its way it will automatically stop until the path is cleared. The SRF02 ultrasonic range finder has a detection angle of 55 degrees, so the mounting position would most likely be in the middle section of the robot. Other factors in deciding to use proximity sensor is our familiarity with this specific proximity sensor and its relative low-cost availability. The SRF02 ultrasonic range finder has a maximum range of detection of 6 meters and requires 5 Volts and 4 mA of current. The output of the SRF02 is linear over its detection range which is another merit to us for using it.

9. User Interface Unit

The user interface allows the user to place an order through the website and check the status of the order, the motor, and the proximity sensor. Major user interface units that we are dealing with are KAEFI's order website, the laptop LCD placed on the robot, and the emergency-stop button.

9.1 Website

KAEFI's website will be mainly used for the users to place orders. Simple PHP website composes of input boxes for the starting point and the destination point and submit button.

When the proper input points are inputted and submit button is pressed, input points will be passed to KAEFI's database. And then, the OADR will get data from the database directly.

9.2 Laptop LCD

The laptop LCD, which is placed on the OADR, will display error messages and status of the OADR such as current location, desired destination, and etc. The data from the database will be passed to the laptop which is connected to the same Wi-Fi network as the database.

Also, the data from the microcontroller, which will be mainly used for the proximity sensor and the motor controller, will be displayed on the laptop LCD to see error messages and status related to the proximity sensor and the motor controller.

9.3 Emergency-Stop Button

It is important to eliminate as many hazards as possible; however, most machines are not as simple as that and there will undoubtedly be hazards that cannot be eliminated.

With this reason and safety first in mind, emergency-stop button will be placed on the OADR to meet ideal emergency stop applications. Main functionality of the button is to stop the OADR immediately by removal of power to the OADR.

9.4 User Interface Verification

To test the user interface, we will perform the following steps:

- Input the starting point and the destination point on KAEFI's website
- On the laptop LCD, display current status or error messages of current order
- Run the motor
- On the laptop LCD, display current status or error messages of the motor
- Place obstacle in front of the OADR so the proximity sensor can detect it
- On the laptop LCD, display current status or error messages of the proximity sensor
- Press the emergency-stop button and check the OADR stops its operation immediately

10. System Testing Plan

Modules will be tested first and integration testing will ensure that different modules will work together. After individual module testing and integration testing are finished, the ideal operation of the OADR is examined with normal and extreme test cases.

10.1 Unit Testing

To verify each module is working properly, following test cases will be used during our development.

- Place an order within the website, and observe that the database is filled with the user's input
- Observe the connectivity between the OADR and the database
- Observe that the QR code is decoded successfully with the camera
- Observe that the motor controller runs the motor properly
- Observe that the movement of wheels by inputs of our path algorithm

10.2 Normal Case I

User Input: The user requests for a delivery

Conditions: Single user requests for a delivery, only one query is in the database.

Expected Result: The OADR delivers the order successfully.

10.3 Normal Case II

User Input: The user requests for a delivery.

Conditions: The user requests for a delivery; another user requests for a delivery or the user requests for another delivery (two queries are in the database).

Expected Result: First requested order gets processed first. After completion of the first order as in Normal Case I, the latter order will be executed as in Normal Case I.

10.4 Extreme Case I

User Input: The user requests for a delivery.

Conditions: The OADR meets an obstacle during its delivery.

Expected Result: The OADR stops immediately and waits until the obstacle is removed from its path. The OADR starts moving again once the obstacle is removed.

10.5 Extreme Case II

User Input: The user requests for a delivery.

Conditions: As the OADR moving for the delivery, the ODAR is off from the path calculated from the path find algorithm which can cause the ODAR off the track.

Expected Result: The OADR executes as in Normal Case I.

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