Autonomous Delivery Robot (ADR)

Project System Concept Description – Part 1

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Team Name: Team 3
Lead Author: Manu Madhu Pillai
Contributing Author(s): Sidney Leigh Molnar, Mukundhan Rajendiran, Xinyi Yang

1. Introduction

1.1. Document Purpose

This document provides an Autonomous Delivery Robot (ADR) system description. The description will be used to guide the development of the Stakeholder Requirements Document.

1.2. References

This section provides a list of references used in the development of this document.

1. HW 5&6 System Concept Description - Template for Parts I & II - V1, by Dr. Tony Barber, 2022.
2. HW3 Team 3 Project Proposal, by Xinyi Yang and team, 2022.
3. Autonomous Delivery Vehicles, by Derick Omondi, 2021. [CrossRef]

1.3. Document Structure

This document follows the structure specified in [1] and it is organized as shown below:

1. Section 1 describes the purpose of this document, organizational structure, and references used by the document.
   1.1. Subsection 1.1 defines the purpose of this document.
   1.2. Subsection 1.2 lists the references used by the document.
   1.3. Subsection 1.3 defines the document's organizational structure.
2. Section 2 identifies the key stakeholders and identifies their roles
3. Section 3 describes the system capabilities and mentions the rationale behind those capabilities.
4. Section 4 defines and describes the Measures of Effectiveness (MOEs) for the system and their association with system capabilities.
5. Section 5 indicates the system's usage from the user's perspective to accomplish their goals.
6. Section 6 describes how the maintenance is carried out by the system.
   6.1. Section 6.1 describes the level 1 operability inspection and service of ADR system
   6.2. Section 6.2 describes the level 2 field inspection and service of ADR system
   6.3. Section 6.3 describes the level 3 functionality inspection and service of ADR system
   6.4. Section 6.4 describes the level 4 software & hardware enhancements of ADR system

2. System Stakeholders and Statement of Need

Table 1 identifies the principal stakeholders for the system and their respective roles.

Table 1: Stakeholder List

ID	Stakeholder	Role(s)	Priority
SH1	**Uber Eats**	Customer, User & Maintainer	Primary
SH2	**DoorDash**	Customer, User & Maintainer	Primary

SH3	**Grubhub**	Customer, User & Maintainer	Primary
SH4	**FedEx**	Customer, User & Maintainer	Primary
SH5	**UPS**	Customer, User & Maintainer	Primary
SH6	**Public Universities**	Potential Customer & User	Secondary
SH7	**Private Universities**	Potential Customer & User	Secondary

3. System Capabilities

The system capabilities and their priorities are documented in Table 2. In addition to this, the system's goals are defined in terms of the lower-level capabilities in Table 2.

Table 2: ADR System capabilities and their priorities

Cap ID	Capability	Rationale	Priority
C1.1	Detect sidewalks, roads, pedestrian crossings, and road signs.	Defines "Path Detection"	1
C1.2	Detect Motor vehicles, pedestrians, cyclists, animals, and similar dynamic obstacles.	Defines "Dynamic Obstacle Detection"	2
C1.3	Detect plants, trees, buildings, railing, and similar static obstacles.	Defines "Static Obstacle Detection"	3
C1.4	Detect and identify other ADRs.	Defines "Dynamic Obstacle Detection"	4
C2	Avoid Collisions with dynamic and static obstacles in the surroundings.	Defines "Safety"	5
C3	Navigate on the given path following road safety laws.	Defines "Navigation"	6
C4	Carry payloads from source to destination as assigned.	Defines" Payload Delivery"	7
C5	Monitor the remaining battery and return to the charging station at the failsafe level.	Defines "Status Monitoring"	8
C6.1	Provide tracking status and maintain communication with the central server.	Defines "Communication"	9
C6.2	Report theft, vandalism, or tampering with	Defines "Security"	10

	the ADR and its payload.		
C7	Open respective payload bay among the segmented payload bays when authorized.	Defines “Security”	11

4. System Measures of Effectiveness (MOEs)

Table 3 identifies the (MOEs) for the system and their associated threshold and objective values.

Table 3: ADR System MOEs

Cap ID	**Attributes**	**Metric**	**MOE ID**	**Definition**	**Threshold Value (units)**	**Objective Value (units)**
C5	Endurance	Continuous operating time	MOE1	Maximum Operational Time on a single charge	> 4 hours	> 8 hours
C3 & C5	Operational Range	Operational radius	MOE2	Maximum operational range (radius) on a single charge	> 1 mile	> 2 miles
C4	Payload	Payload Capacity	MOE3	Maximum payload capacity	> 50 lbs	> 100 lbs
C5	Charging Time	Time to charge	MOE4	Empty to full charging time	< 4 hours	< 2 hours
C6	Communication Range	Radius for optimal communication	MOE5	Maximum communication (telemetry) range from central server	> 1 mile	> 2 miles
C1 & C2	Collision avoidance	Farthest object detected	MOE6	Perception Range for Collision avoidance	> 66 ft	> 165 ft
C3	Operational Speed	Maximum safe navigational speed	MOE7	Maximum Operational speed	> 5 mph	> 15 mph

5. System Operational Concept

The intended users of the system of interest are faculty, staff, and students on large university campuses. Users can order a delivery that can then be transported from one end of campus to the other. Once an order has been placed by the user in the customer's app (primary stakeholders like UberEats and Grubhub), an ADR is deployed from the nearest warehouse to the pickup location. The ADR has to navigate through the streets and sidewalks on the university campus and the surrounding region.

This puts the ADR in a dynamic environment where it will need to avoid several moving obstacles such as pedestrians, cars, bikes, and scooters. Conversely, pedestrians and people operating vehicles must know to navigate around the ADR. As such, the ADR will have a signaling structure that exists at eye level for greater visibility to cars and pedestrians.

ADR uses obstacle avoidance sensors to detect and avoid obstacles. Aside from the dynamic aspects of a university campus, the ADR will need to be able to navigate along sidewalks and roads, avoiding stairs, construction, and otherwise dangerous terrains. Additionally, for campuses that face seasonal changes, the ADR will need to travel through various types of inclement weather such as rain, high winds, or snow.

When the ADR reaches its source, it requires a user verification QR code to open the package storage compartment of the ADR. When the sender scans the QR code painted on the ADR, it is authenticated through the app and the information is sent to the ADR via the central server. The control system verifies the code before opening the storage compartment by sending a signal to the lock system. Thus, the assigned payload bay opens allowing the sender to place the package to be delivered.

The sensor system sends sensor data to the control system to check if the payloads are inside ADR and if there are any static and/or dynamic obstacles in the surroundings. The control system controls the ADR to avoid obstacles, navigate to destinations, and make sure that the payloads are put into the ADR at the source (restaurants/stores) and taken out at the destination (users) by using the data received from the sensor system. The motion system receives directions from control and derives power from the power supply to move (left/right/forward/backward/stop). The wireless communication system sends the real-time location of the ADR from the sensor data to the user by a mobile application.

Once the ADR makes it safely to the intended location, users will be able to access their order in the secured compartment using the QR code authentication. The ADR moves on to the next order, repeating this process until it requires recharging. In case there are no new orders or the ADR requires recharging, it returns to the nearest warehouse.

The management system provides maintenance and logistical support for the ADRs including charging, cleaning, and regular maintenance.

6. System Maintenance Concept

There are mainly 4 levels of maintenance for this system. The period of maintenance will vary according to the level of maintenance described below. The maintenance shall primarily take place on the following four elements of the ADR system: electro-mechanical system, sensors, firmware, and software application.

6.1. Level 1: Operability Inspection & Service of ADR System

At this level, the system is checked and maintained on a daily basis. This level mostly consists of overall inspection and cleaning of the system. The tasks are cleaning the sensors like cameras for better visibility and inspecting the electro-mechanical body for cracks, dents, and any other damages which could affect the operation of the ADR, and also cleaning and removing any leftover items in the individual storage system. The time required to conduct this level of maintenance would be around five to ten minutes for each ADR.

6.2. Level 2: Field Inspection & Service of ADR System

Second-level maintenance includes a little bit of in-depth inspection of the ADR. It includes the inspection of mechanical and electronic systems on board the ADR. Tasks like checking and fixing lubricating levels, sensor calibration & wheel alignment. This level of maintenance check can be done using the user manual given to the user and the self-diagnosis feature in the ADR. The time required to conduct this level of maintenance would be around thirty to sixty minutes for each ADR. This level of maintenance is scheduled once a month.

6.3. Level 3: Functionality Inspection & Service of ADR System

All the components have a life span until which they would work efficiently. The components can be mechanical parts such as wheels, motors, and suspension systems and they can also be electrical components like batteries, sensors, and wirings. These components are inspected and the decision is taken to either service the part for extended life or replace it with a new part. This decision can be taken by the user as the details regarding each component and its life span, range, and other specifications would be provided in the user manual. The time required for maintenance shall vary on the hours and conditions under which the ADR was utilized. This user may order spare parts and shall be provided with a manual to replace the parts. Further assistance such as a technician would be sent if necessary.

6.4. Level 4: Enhancements of ADR System

The firmware in the ADR would be upgraded based on feedback and the data collected while the ADR is operating. The firmware is updated wirelessly via the central server during charging or at stand-by in the warehouse. Upgrades in firmware mainly focus on eliminating flaws hindering the efficiency and safety of the system. Enhancements can be requested and accommodated due to the different climatic and environmental conditions of the locations.

Multiple ADRs aid in an efficient workflow. Even if one of the ADRs fails due to a problem, another ADR with the availability of space could take over the task of the malfunctioning ADR, thereby not affecting the workflow. The malfunctioning ADR can be commanded or manually overridden to either return to the base or stop at a nearby safe location for further inspection of the issue. If the ADR stops abruptly and is immobile, assistants/technicians are sent to the location to assess the severity of the situation and repair the ADR accordingly. Depending on the severity of the issue, the technicians at the warehouse will resolve it or send it to the manufacturer.

The application used by the user and the customer is also updated according to the feedback and data collected for seamless usage of the application for the user. As the number of users increases, server load handling capacity and the number of ADRs would be appropriately updated.