Drone Delivery: Heuristic Algorithm using Task and Path Planning

Varun Lagadapati and Cyrus Bilpodiwala
University of Maryland

***Abstract*—Drones have been getting adopted in many areas of business, be it delivering food, conducting aerial surveillance, disaster relief, parcels delivery, etc. In this study, we propose a method of making drones reliable to deliver items given several constraints. We used Python in Blender to create a drone simulation that models a drone delivering packages to a specific location in an optimal amount of time. The drone's main goal was to dodge any obstacles (trees and houses) that it encountered in the way and then plan a path towards its intended destination. In this project, we created a path planner for the DJI Tello drone in order for it to deliver items.**

I. Introduction

Drones have been useful in a plethora of applications, for instance, they have been used to deliver packages, surveillance purposes, monitoring climate change, executing search operations during a disaster, etc [12]. Over the past few years, they have become central to the functions of various organizations and have pierced through areas where certain industries were stagnant or lagging behind. They are anticipated to transform the shipping business area given that shipping companies have started experimenting with them [3]. They have created advantages like economic savings and environmental benefits, while also reducing risks to human life [12].

It has been debated whether or not drones can be entirely reliable for performing deliveries. As a result, they are not a cure-all for all problems, there appear to be some drawbacks of relying on them a lot, for instance, they can get hacked easily, their vulnerability to bad weather conditions, and their inability to transfer data in a reliable amount of time [5].

A. Overview

In this paper, we propose a method of delivering items using a DJI Tello drone that has minimal sensory capabilities, payload capabilities, limited battery capacity and controls. For this assignment, we could only use the limited capabilities of the drone and we essentially assumed that in our simulation that the drone has picked up the materials and is ready for dropping them off. We tackled the challenges by making our drone avoid the obstacles that it encounters in its path and by programming our drone to reach both its destinations; the data is provided in frames.

Our approach will address the problem of fast and efficient delivery by ensuring that the drone goes to the delivery locations. Our simulation accounts for all the depth frames; it adjusts the velocity based on several conditions, as well.

B. Problem Definition and Contributions

For this assignment, we had the task of modeling a delivery drone in Blender assuming the constraints of payload capacity, limited sensory capabilities, and, limited flight abilities. In this case, the drone couldn't fly above, but it could only fly towards the left or right [7]. It couldn't carry anything and thus, we couldn't represent a real-world drone that could deliver items from one place to the other. In addition to this, the drone can't plan its path towards the destination. The first was that we assumed that the drone is in the static scene and the other was that the drone already has the packages so it just has to deliver them to the designated spots.

C. Organization

This report is structured into sections Related Work, Approach, Experiments, Conclusions, Acknowledgement, and Distribution of Work. In the Related Work, we include the latest research on the solution to the problem we are addressing. In the Approach, we talk about our methods as approaches and break them into sections. The two methods that we will discuss are task planning and path planning. We explain each of them in detail and include examples. In the Experiments, we describe the experimental setup by including the scene and drone we used. We also describe the code trials conducted for our simulation and show images. In the Conclusions, we restate our idea for this project and explain what we achieve from the results based on the trials from the experiments. We also include other ways to improve our results that takes the research forward. In the Acknowledgement, we thank the people who reviewed this paper, gave suggestions for improvement, and helped in experiments but did not become authors. In the Distribution of Work, we include how we divided the work for the entire project.

II. Related Work

We focused all of the related work onto the ideas that we used in our simulation: task planning and path planning. We found articles that talked about many of the ideas that we used to make our drone simulation.

Description: This article talks about how drones can be used to make delivery of items easier. It also talks about how drones can be used for delivering food, performing farming activities, and transporting items from one place to another. Particularly, drones can be used for performing farming activities because they can capture photos that help farmers to monitor irrigation equipment, pesticides and fertilizers, and gather plant and environmental data. The data that the drones provide can assess the fertility of the crops so this allows farmers to accurately add fertilizer, reduce wastage, and have irrigation systems [5].

Description: This article talks about the improvement of the delivery drones. One of the drawbacks of using drones for deliveries is that they don't seem to deliver as quickly to customers who are located far from the warehouse. It proposes an alternative system model based on a public transportation network; it also has the ability of enlarging its delivery range. They present a stochastic model to characterize the path traversal time and develop a label setting algorithm to construct the reliable drone path. In addition to that, they also considered battery life of the drone to determine if a certain path was feasible, too [11].

Description: Path planning is a challenge for Unmanned Aerial Vehicles and the reasons range from vehicle dynamics to the existence of surrounding vehicles. In this study the authors propose a path planning model called "Model Predictive Control", that decides the modes of maneuvers. They modeled the vehicles as polygons and to avoid collisions, they create a set of constraints. The model automatically decided the mode of maneuvers under an optimized network; in their results they found that their path planner has been effective at generating a safe and comfortable path for vehicle [15].

Description: The main idea of this paper is path planning, which becomes one of the important ideas that are connected to autonomous vehicles. This deals with finding an optimal path given the obstacles, kinematic constraints and others that will affect the feasible paths. The main idea of this paper is a system which can automatically generate an optimal feasible trajectory and then control the vehicle to track exactly on this path from any given starting points to given destination points from a map subject to vehicle physical constraints on obstacles, speed, steering angle, and etc [16].

Description: The authors of this paper develop a heuristic approach for the optimal delivery of items in a system combining a truck and a UAV. The model determined the optimal allocation of customers to truck and UAVs, the optimal route sequence of the truck, and the optimal launch and reconvene locations of the UAVs along the truck route. In this article, the truck and UAV operations were synchronized, meaning, one or more UAVs travel on a truck, which serves as a mobile depot. Deliveries were made by both UAVs and the truck. While truck followed a multi-stop route, each UAV delivered a single shipment per dispatch. The truck and drone were working together [17].

Description: This article talks about using drones for the purposes of parcel delivery. In this work, the authors provide an analysis on benefits and drawbacks in using drones in the parcels delivery process. They analyze three different transportation systems with incremental use of drones for the delivery. In particular, they address the problem of delivering parcels without a drone, known as the vehicle routing problem, the problem in which the deliveries are performed by a fleet of drones starting from the central depot, and a hybrid transportation system where the classical vehicles are equipped with drones [18].

Description: This article deals with the development of a new car named Clothoid that is meant to compete with Hyundai. This model is meant to work as an autonomous system that generates the shortest path to reach a specific destination. It implemented Global Path Planning (GPP), Decision Making, Local Path Planning (LPP) and the Low-level Control System on I-30 platform called Clothoid. The algorithms used are implemented in the ROS framework, which is written in C++ and Python in Linux Operating System. They performed experiments that showed that the vehicle could work in both simulator and proving ground [19].

Description: This article deals with path planning in rovers; it deals with robots that depend on direction to plan their paths. Optimal path planning is considered for rovers. Efficient and safe path planning is an important area of research for robots; path planning for rovers has motivated the research into this area. The path planning problem where the environment is approximated using a graph can be solved using graph algorithms. The path planning of a rover is extended to consider direction in tip over risk, which is modeled using direction dependence. In this model, solar energy consumption, minimal path planning, obstacle avoidance, and soil risk are all considered. In this article, the authors use the Ordered Upwind Method to solve the rover path planning method and find that it is faster than the Fast Marching Method (FMM). The difference is that the FMM did not model the tip over risk, while the OUM method is shown to solve the problem of path planning. Contributions include a more accurate model of tip-over risk and the introduction of solar energy that is used in optimal path planning for rovers based on the direction [1].

Description: This article includes a path planning algorithm to avoid obstacles and efficiently calculates a path from the starting position to the destination position with the constraint of limited computing power. This algorithm is also heuristic like our algorithm but this algorithm involves finding the shortest path and that differs from the lowest energy path from the energy that was spent in changing direction. From the heuristic algorithm, the main conclusion was that it lead to a lower overall energy consumption without increasing computation time drastically [3].

Description: This article talks about how path planning is involved with an autonomous quadcopter based delivery system. The proposed algorithm plans a proportional position and altitude controller that are used to track the path. This algorithm includes a combination of sampling based

Bidirectional RRT algorithm and improved Artificial potential field (APF) algorithm. The first algorithm is more goal-oriented and the second limits the search space to a smaller section of the environment in turn reducing the execution time. The main difference is that this article includes the quadcopter or quadrotor but we are using the DJI Tello drone [4].

Description: This article explains that drones can execute air operations which are difficult for manned air crafts to perform and that drones cause savings and environmental benefits while reducing the risks that humans face. The current design that drones are built around has a major flaw: the architecture is organized in a loosely couple monolithic boards and these boards contain the same usual components as the computer [12].

Description: This article includes a new approach called the "vehicle routing problem" for drone delivery, that generalizes the traveling salesman problem. The authors propose two vehicle routing problems (VRPs) for drone delivery. The first reduces costs subject to a delivery time limit while the other reduces the overall delivery time subject to a budget constraint. The authors validate an energy consumption model for the drones and demonstrate that energy consumption varies approximately linearly with payload and battery weight. Then, they use this approximation to derive mixed integer linear programs for VRPs. The results confirm the importance of reusing drones and optimizing battery size in drone delivery VRPs [7].

Description: This article deals with the problem of autonomous vehicles running into an unstructured roads. In order to generate a safe and smooth path in this situation for the autonomous vehicle to run, the authors proposed an improved heuristic graph search path planning algorithm to solve the problem by considering both the obstacle constraint and vehicle model. The kinematic constraints of the vehicle are considered, too. Regarding the efficiency and safety, the obstacle constraint and vehicle motion were taken into account when making cost and heuristic functions [8].

Description: This article describes the concept of making drone delivery practical. There are five different types that drone delivery can be used for and they include merchandise, courier, food, and passenger deliveries, and humanitarian aid. Achieving the optimal time is considered for each of these deliveries. However, there are four technology challenges and they include capability, efficiency, coordination, and AI at the edge. Unlike the other three challenges, the AI at the edge is an overarching technological challenge that affects the other three challenges and computational tasks involved are path planning under constraints, image processing and recognition, and risk assessment [9].

Description: This article explains that drones can be used extensively for delivering tasks in the future and that task planning is involved. A new idea that is different from our idea that is mentioned in this article is reinforcement learning. Reinforcement learning is the branch of AI and is studied for drone delivery so the drones are trained to fly to destinations in a neighborhood environment with plenty of obstacles like trees, cables, cars, and houses. The main goal is that the drones have to avoid visible obstacles to reach their goal and there are checkpoints that save a trained model to improve the results [10].

Description: This article focuses on a real-time trajectory planning problem for autonomous vehicles driving in realistic urban environments. The authors adopt a hierarchical motion planning framework to solve the navigation problem. First, a rough reference path is extracted from the digital map using commands from the high-level behavioral planner. The conjugate gradient nonlinear optimization algorithm and the cubic B-spline curve are used to smoothen and interpolate the reference path sequentially. To follow the refined reference path as well as deal with static and moving objects, the trajectory planning task is decoupled in lateral and longitudinal planning problems within the curvilinear framework. A rich set of kinematically feasible path candidates were generated to deal with the dynamic traffic both deliberatively and reactively. The velocity profile generation was performed to improve driving safety and comfort. After that, the generated trajectories were carefully evaluated by an objective function, which combines behavioral decisions by reasoning about the traffic situations. The optimal collision-free, smooth, and dynamically feasible trajectory is selected and transformed into commands executed by the low-level lateral and longitudinal controllers. They conduct experiments that demonstrate capabilities and effectiveness of their proposed plan and algorithms to handle a variety of driving scenarios like static and moving objects avoidance, lane keeping and vehicle following while respecting all traffic rules [14].

Description: This article talks about maneuver planning for autonomous unmanned vehicles and the ways to have that are through three components: the perception of the environment and the vehicle localization in it, the trajectory planning and the vehicle's control. The work in the study covers the trajectory planning module and serves as an extension to the previous works where they developed an algorithm for local trajectory planning based on the Clothoid Tentacles method. A strategy that satisfies the vehicle dynamics constraints as well as the road rules and the security measurements is presented to execute the overtaking maneuver.This method is used to overtake an obstacle and turn back to the reference trajectory defined by the right lane of the road. This method is improvised by studying the overtaking maneuver, and generating a suitable trajectory for lane changing maneuvers taking into account the vehicle dynamics, road rules and security measurements [2].

Description: This article deals with the optimal plan for indoor goods delivery using drones. This optimal planning is necessary because it saves the drones' batteries and task accomplishment time. There are figures that describe the real-time setup and a frame from a movie of the real-time experiments and show the sketch of movement and delivery sequences for the drones. The authors make sure that their research aims at recovering an optimal solution for a VRP associated with the drones. They also describe their future work involving on-line path planning and specific collision avoidance techniques that are suitable for multiple teams of drones [13].

Description: This article talks about planning in relation with unmanned vehicles. Although this article deals primarily with vehicles on a roadway, it deals with many of the ideas we have used to build our simulation. Autonomous vehicles have problems planning a path in traffic and the authors model the interaction between the same vehicle and its environment as a Markov decision process(MDP) and attempt to learn the driving style of a typical driver. The autonomous vehicles are able to detect the environment and navigate without driver input using techniques like radar, lidar, ultrasound, etc. This paper focuses on reproducing the decision making of an expert driver and duplicating the optimal driving strategy involving actions like lane-shifting, lane and speed maintaining, accelerating and braking, by considering the random driving behaviors of the environmental vehicles in traffic [20].

Description: This article focuses on a simple and efficient algorithm for drone path planning. The critical task for the drones is to compute effective flying paths that allow the drones to reach their destinations while avoiding obstacles and minimizing the amount of energy that they need to consume. This path planning algorithm can generate an optimal or close to an optimal path that limits the amount of energy that a drone needs to consume to arrive at its destination. There are tables and graphs that describe the length of the paths, running times, and variables used in the algorithm. The authors conclude that this algorithm is simple and has the potential to be energy efficient [6].

III. Approach Sections

This section is divided into two approach sections. One is task planning and the other is path planning. Both of these sections are described.

A. *Task Planning*

Task Planning involves a sequence of tasks that a drone must execute to achieve the goal [8]. The standard way in which the drone does this is through perceiving a location and computing paths in a 3D environment [7]. In our case, the drone starts by taking off from the launch pad with the packages and flies to the 1st delivery spot avoiding trees and houses. Next, the drone delivers the packages to this spot first and takes off from that spot. Finally, the drone repeats the previous steps for the 2nd delivery spot and returns back to the launch pad. This notion of task planning is meant to enable drones to complete tasks the same way that humans do, but in a different manner, with programmed instructions.

B. *Path Planning*

Path Planning is the ability of a drone to plan its path in order to avoid obstacles and its main application is to guide a drone or UAV to reach a certain destination; it also deals with searching a feasible path taking the vehicle's geometry, the surroundings as well as the kinematic constraints [16]. This is one of the hardest things to achieve in a unmanned vehicle, and in addition to that, there have been no efficient path planning approaches [15]. A similar idea was used to generate a feasible optimal trajectory and then control the vehicle to track exactly on that path from any given starting points to any given destination points from a map subject to the vehicle physical constraints on obstacles, speed, steering angle, and so forth [16]. Basically put, this is the idea where an intelligent agent is planning its path based on its inputs. In this case, the agent is performing actions based on sensory perception. Over here, the robot plans a path that's collision free and transports the drone from its starting point to the destination. In our project, the drone had minimal sensory capabilities so it couldn't detect the obstacles in its path.

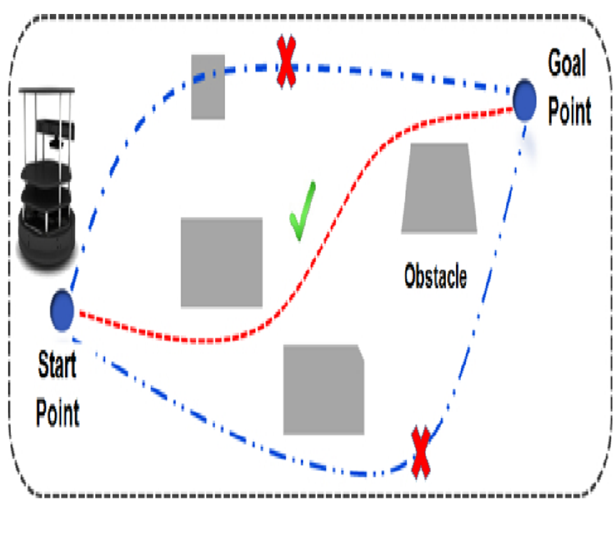

Fig. 1. Drawing representation of Path Planning

This image shows an routing plan for a robot where it avoids all sorts of obstacles in its path.

[1]

[1] Path Planning. (2014). Semantic Scholar. https://d3i71xaburhd42.cloudfront.net/834a9af3288672c5208a0c3f1f5f2df1fd5baf45/14-Figure2.1-1.jpg

IV. Algorithm

In this algorithm, we traverse the Depth frame set and then, we accounted for all the cases e.g. when the drone was on the left corner of the screen, right corner, etc. We account for three basic cases where the drone reaches the left most and the right most position. In the case where it is at the left corner, we increment velocity otherwise at the right corner, the velocity is decremented. In the third case, the velocity is assigned 0. Therefore, the drone is not moving in the last case. The main idea of this algorithm is to account for the cases where the drone will stop or go on and then while it moves, the distance to goal is decremented by one. The pseudocode is below.

Algorithm 1 Drone Delivery Path Algorithm Pseudocode

$D \leftarrow distanceToGoal$
$Velocity.x \leftarrow xPositionOfDrone$
$DepthFrames[] \leftarrow Arrayofframes$
$x \leftarrow 0$
$y \leftarrow 0$
for x in Array of frames **do**
  for y in Array of frames **do**
    if $x \leftarrow 1$ and $y \leftarrow 1$ **then** $Velocity.x \leftarrow 2$
    else if $x \leftarrow 1$ and $y \leftarrow 240$ **then** $Velocity.x \leftarrow -2$
    else $Velocity.x \leftarrow 0 \quad D \leftarrow -1$
    end if
  end for
end for

V. Experiments

In this drone simulation, we basically had almost the same setup as ASN3. But in this case, we attempted to modify the drone's x-direction velocity to make it move in the x-direction left or right. Our animation had some trees and houses and then, three flat surfaces were used to represent the drone's starting position, the first destination and the second one.

We conducted two code trials for the simulation. We changed the code in ASN3 to account for the two destinations and the starting position. In this case, what we did was we used the location of the drone and the destinations to make the planner code. We traversed the depth map and then changed the velocity of the drone based on multiple conditions but in the other cases, it was adjusted to account for the distance between the camera and destinations. There are four figures that describe the simulation.

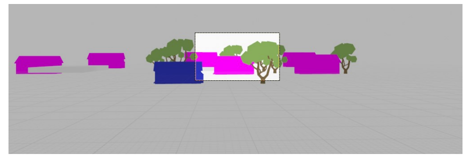

Fig. 2. The drone camera's front view

This image shows the camera viewpoint of the drone. There are trees and the pink and blue houses. The white box represents the drone's line of sight that highlights the trees and houses in the drone's path so drone has to move away from obstacles.

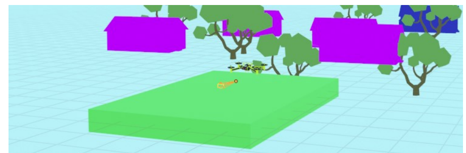

Fig. 3. Drone at first destination

This image shows the drone at the first destination which is represented by the green flat cube avoiding the trees and the houses. The drone is ready to go to the second destination.

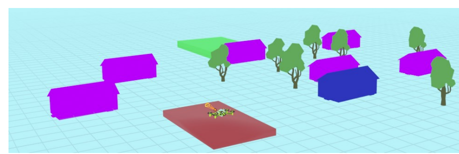

Fig. 4. Drone at second destination

This image shows the drone at the second destination which is represented by the red flat cube avoiding obstacles. The drone is ready to go back to the starting position.

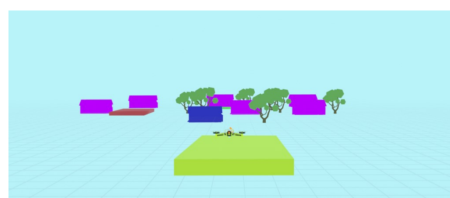

Fig. 5. Drone at starting position

This image shows the drone at its starting position which is represented by the yellow flat cube and that is the launch pad at the end of simulation.

In this project, we used the simulation as a means of evaluating how the drone was performing its actions. We generated the outputs in a file and used them to assess our current status. We also use the total running time of the simulation to evaluate the effectiveness of our approach.

Trial 1: In this first trial, we experimented with the graph editor and made changes to the drone's position and saw that the drone was starting to move closer towards its location, but it wasn't doing everything as we expected it to.

Trial 2: In this second trial, we experimented with code in

Python to see whether the drone was actually executing the instructions given to it. We created depth frames that would account for all the frames in the image and from that we would determine if the drone reached its target.

VI. Conclusions and Future Work

In this study, we did achieve a few things: we simulated a drone delivering items, we accounted for the obstacles in the way and made sure that it created a well laid out path plan. In the future, we plan to improvise our Blender code to account for all the situations that the delivery drone will encounter, for instance, making sure that the drone stops at the first delivery location and then ensuring that it avoids obstacles along the way. In addition to that, we plan to ensure that our idea is actually working by troubleshooting issues that occur during the execution of the code and making sure that there are outputs generated.

VII. Acknowledgement

The authors would like to thank Dr. Nitin for reviewing the paper and providing helpful feedback. The authors would also like to thank the FIRE department for providing us a good experience with this stream.

VIII. Distribution of Work

We distributed this work equally on the entire project by collaborating our ideas for the project. Next, we sticked with one main idea and this was to make sure that the drone delivers the goods to the delivery spots in an optimal amount of time. We gathered feedback and revised our presentation and simulation.

References

[1] Shum Alex, Morris Kirsten, and Khajepour Amir. Direction-dependent optimal path planning for autonomous vehicles. *Robotics and Autonomous Systems*, 2015.

[2] Chebly Alia, Talj Reine, and Charara Ali. Maneuver planning for autonomous vehicles, with clothoid tentacles for local trajectory planning. *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, 2017.

[3] Chatterjee Amrita and Reza Hassan. Path planning algorithm to enable low altitude delivery drones at the city scale. *2019 International Conference on Computational Science and Computational Intelligence (CSCI)*, 2019.

[4] Krishnan Athira, Jisha V., and Gokulnath K. Path planning of an autonomous quadcopter based delivery system. *2018 International Conference on Emerging Trends and Innovations in Engineering and Technological Research (ICETIETR)*, 2018.

[5] Dane Bamburry. Drones: Designed for product delivery. *Design Management Review*, 26(1):40–48, 2015.

[6] Fu Chen, Gopi Gugan, Roberto Solis-Oba, and Anwar Haque. Simple and efficient algorithm for drone path planning. *ICC 2021 - IEEE International Conference on Communications*, 2021.

[7] Kevin Dorling, Jordan Heinrichs, Geoffrey Messier, and Sebastian Magierowski. Vehicle routing problems for drone delivery. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 2016.

[8] Xingxing Du, Xiaohui Li, Daxue Liu, and Bin Dai. Path planning for autonomous vehicles in complicated environments. *IEEE International Conference on Vehicular Electronics and Safety (ICVES)*, 2016.

[9] Frachtenberg Eitan. Practical drone delivery. *Computer*, 2019.

[10] Munoz Guillem, Barrado Cristina, Cetin Ender, and Esther Salami. Deep reinforcement learning for drone delivery. *Drones*, 2019.

[11] Hailong Huang, Andrey Savkin, and Chao Huang. Reliable path planning for drone delivery using a stochastic time-dependent public transportation network. *Transactions on Intelligent Transportation Systems*, 2020.

[12] Mahmoud Hussein and Réda Nouacer. Towards an architecture for customizable drones. *44th Annual Computers, Software, and Applications Conference*, 2020.

[13] Marius Kloetzer, Adrian Burlac, Gabriel Enescu, Simona Caraiman, and Cristian Mahulea. Optimal indoor goods delivery using drones. *2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, 2019.

[14] Xiaohui Li, Zhenping Sun, Dongpu Cao, Zhen He, and Qi Zhu. Real-time trajectory planning for autonomous urban driving: Framework, algorithms, and verifications. *IEEE/ASME Transactions on Mechatronics*, 2016.

[15] Chang Liu, Seungho Lee, Scott Varnhagen, and Eric Tseng. Path planning for autonomous vehicles using model predictive control. pages 174–179, 2017.

[16] Vu Minh and John Pumwa. Feasible path planning for autonomous vehicles. *Mathematical Problems in Engineering*, 2014.

[17] Mohammad Moshref-Javadi, Ahmad Hemmati, and Matthias Winkenbach. A truck and drones model for last-mile delivery: A mathematical model and heuristic approach. *Applied Mathematical Modelling*, 80:290–318, 2020.

[18] Luigi Di Puglia Pugliese, Francesca Guerriero, and Giusy Macrina. Using drones for parcels delivery process. *Procedia Manufacturing*, 42:488–497, 2020.

[19] Nam Dinh Van and Gon-Woo Kim. Development of an efficient and practical control system in autonomous vehicle competition. pages 1084–1086, 2019.

[20] C. You, J. Lu, D. Filev, and P. Tsiotras. Advanced planning for autonomous vehicles using reinforcement learning and deep inverse reinforcement learning. *Robotics and Autonomous Systems*, 2019.