

Department: Head

Increasing Consumer Drone Safety Through An IoT Based Custom Illumination System

Shuai Hao

University of Florida, USA

Boyi Hu

University of Florida, USA

Mustafa Ozkan Yerebakan

University of Florida, USA

Abstract—Consumer-based drone applications have been increasing rapidly in recent years. Most of these applications, such as aerial surveillance, crop dusting, and real estate photography rely on frameworks that are based on Internet of Things (IoT). Although solutions have been proposed to security issues due to connectivity, physical safety issues have not been sufficiently discussed. To solve one such issue, the conspicuousness of drones during flight, we have proposed an illumination system that can adapt to different weather conditions using an IoT framework. To test the feasibility of our illumination system we conducted two tests, a power consumption test, and a human-in-the-loop assessment. The power test showed different illumination configurations did affect power consumption. The human-in-the-loop assessment demonstrated the effect of illumination on distance perception and how sunlight levels affected the drone's preferred illumination color. As drones begin to operate in more crowded spaces such as cities, the need to ensure the safety of the public will be paramount. Through this prototype, we aim to provide designers with guidance on how to consider illumination for safer drone operations. In future studies, we plan to explore using illumination to increase safety and congruence in future application areas such as delivery.

SINCE the past decade, the interest in Unmanned Aircraft Systems (UAS), or more commonly known as "drones", and their applications has been growing

steadily. Although their use for military applications began in the early 1990s [1], civilian drone use have been confined to hobbyists at the consumer level until recently. This was mostly due to the lengthy process of obtaining commercial operation permits and the unclear nature of operational regulations. Beginning in 2016, the FAA began a campaign to clarify regulations relating to drone operation [2]. The European Union

Digital Object Identifier 10.1109/MCE.2022.Doi Number

Date of publication 00 xxxx 0000; date of current version 00
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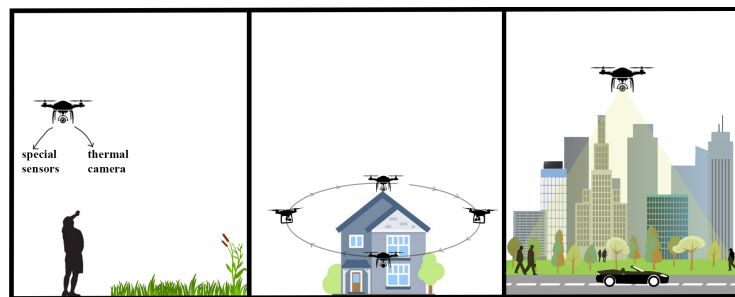


Figure 1. Example Applications for Consumer Grade Drones. Left to right: Crop monitoring, Real Estate Photography, Aerial Surveillance

(EU) followed suit in 2019 when they established an EU-wide framework for drone regulations by considering existing frameworks from International Civil Aviation Organization (ICAO) and the FAA [3]. Finally in 2020, the International Civil Aviation Organization (ICAO) established general frameworks Part 101 and Part 102 to establish general guidelines for operations globally [4]. The ease of regulations allowed for large scale drone adoption for both commercial and consumer use..

Currently, there are approximately 1.7 million registered drones in the United States with 520 thousand of them being commercial [5]. Another country with a large drone presence is China, which had 517 thousand registered drones in 2020 [6]. This number will only continue to rise as regulations around the world continue to be formalized and relaxed. For example, the FAA started to allow drones to operate above people without requiring operational waivers. This has removed a major obstacle for operations such as delivery and transportation [7].

Even compared to their commercial grade counterparts, which tend to be much bigger and carry larger payloads for applications such as crop dusting [8], current consumer grade drones are also capable of performing a multitude of tasks. Tasks such as agricultural inspection [9], aerial surveillance [10], and real estate photography [11] have been good fits for consumer grade drone due to their high degree of mobility and the quality of their cameras.

These applications rely on real time data to both inform drone operators and increase their situational awareness during operations. This has been made possible by the introduction of IoT systems, which enabled large amounts of data to be collected, stored, and analyzed without the need for bulky computers. Thus, fundamentally changing how we interact with

technology [12]. Drones have already shown potential in IoT based systems, with researchers proposing to use them as mobile data collection hubs [13], for detecting objects [14], and even providing internet access to rural communities [15]. Drone-based IoT systems have also been suggested for use in future supporting deliveries and transportation.

Ubiquitous drone deployment still faces significant challenges. One of such challenges is ensuring the safe operation of all drones - both piloted and autonomous. IoT methods have been suggested as a way solve these problems. For example, IoT methods have been proposed in establishing a governed airspace for drones called Internet of Drones (IoD). IoD is defined by Gharibi et al. as a "layered network control architecture designed mainly for coordinating the access of unmanned aerial vehicles to controlled airspace, and providing navigation services between locations referred to as nodes"[16]. Similar to how different airports govern the movement of airplanes in the respective airspaces, Gharibi et al. proposed Zone Service Providers (ZSPs) to govern drone movement. However there are security issues with the IoT frameworks themselves, such as spoofing and jamming [17]. In order to combat security related issues in IoT, blockchain technologies [18] and elliptic curve cryptography [19] have been suggested to strengthen the networks that are used to communicate with the different components of IoT frameworks.

The other major safety issue facing drone is ensuring they are conspicuous to its surroundings during operation. One common solution deployed in other areas of aviation is the use of illumination. Techniques using different colors and patterns have been mainstays in communicating the direction of movement of planes and the layout of the runway. Illumination is especially important in nighttime operations when the

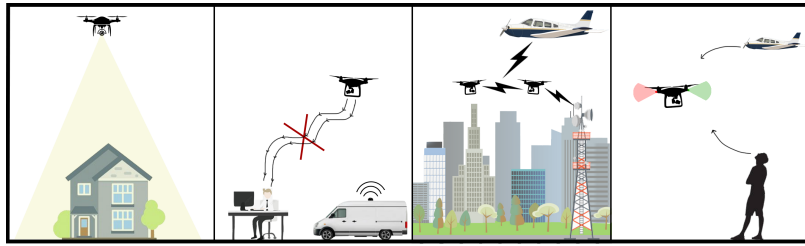


Figure 2. Some Safety Issues Facing Consumer Drones. Left to right: Trespassing and illegal surveillance, Attacks on IoT, Communication between Flying Agents, Drones Conspicuousness in the Sky

only natural source of light is moonlight. Conspicuousness during flight is not only important for ensuring the safety of humans, but to ensure the success of future drone operations themselves, both piloted and autonomous. Apart from alerting other agents to a drone's whereabouts, illumination in drones would be vital as many drones use stereovision for obstacle avoidance. Without appropriate visual cues, the drone would essentially be flying "blind".

Although quite prevalent in general aviation, this aspect of illumination is largely absent in drone regulations and related scientific endeavors. This study will introduce an illumination system that addresses these needs. Taking inspiration from studies that have used IoT frameworks to solve security problems for drones, our illumination system is also based upon an IoT platform. To ensure the security of our illumination system, we also utilize blockchain technology for secure communication. We envision this platform to be used as a safety feature to ensure drones can operate in any ambient lighting conditions. Additionally, with our system we hope to inspire further research and regulations development on illumination for drone operations.

Our manuscript is structured as follows: We first give an overview of our proposed IoT framework and its specific components. Then we present the results of our two validation experiments: The power consumption test in which we investigate how much power our system uses in different circumstances, and the human-in-the-loop assessment, in which we test our system in the field while investigating the effect of distance and illumination color on the distance perception of humans. Our manuscript ends with a discussion on the limitations of our framework and future research we plan to pursue.

SYSTEM DESCRIPTION

System Overview

We have proposed a system which is comprised of three main parts:

Original drone: In order to address the safety issue of drone visibility, we focused on making the drones conspicuous. Specifically, we focused on the illumination, as it has a precedence in the aviation industry. We have elaborated on how we came to select illumination as the primary medium later in the manuscript. After surveying illumination systems [20], we decided that an external illumination system would be the best fit for our case. However, there is another reason why we selected external illumination. One of the emerging areas for this type of application is drones' involvement in providing various cues to humans in an efficient manner, thus enhancing general situational awareness. Drones are flexible to deploy and can fly very close to human targets, which can assist with the dissemination of necessary news updates in difficult circumstances.

In selecting which off-the-shelf drone to implement in our framework, we considered several factors: the battery capacity of the drone, the body type (whether or not it landed on skids), and payload capacity. We eliminated drones that did not have a landing skid, as mounting attached systems on top of the drone would have affected the stability during flight. Per these requirements, we elected to use a DJI Phantom 3 drone in our research.

Attached system: This part of the system encompasses the direct modifications we have made on the drone itself and represents the IoT applications of our system. This unit is designed to be configurable, allowing for different modules to be put in or removed depending on requirements. The application-oriented unit is to be accessed through the ground station only

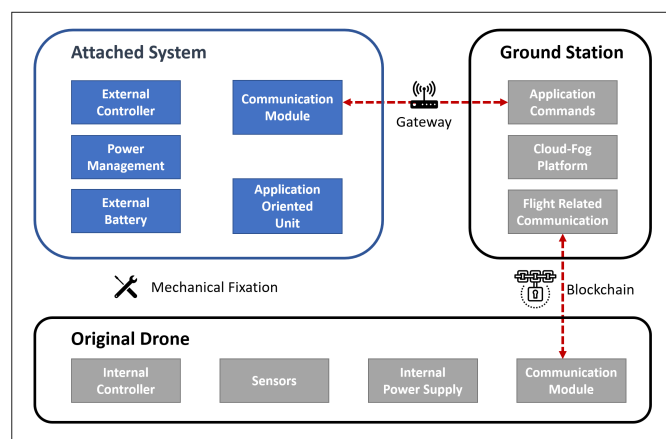


Figure 3. Proposed System Overview with the Three Main Parts and Their Components

via a separate communication module.

Ground station: Deployment and operation of drones require utilization of a set of ground-based hardware, software, and technologies including IoT, Cloud computing, Fog computing, and Blockchain. The application-oriented unit will be directly controlled by the ground station according to IoT gateways. Cloud-Fog platforms are a series of nodes that receive data from IoT devices in real time, and provide localized services to these applications. At the same time, all the services and communications regarding the flight would be deployed via Blockchain.

System Architecture

We have framed our discussion of our system in four broad categories: external controller selection, power supply, mechanical modification, and the IoT framework.

External Controller Selection: A Raspberry Pi computer is used as the external controller in this project, which is widely used by computer and electronic hobbyists, due to its adoption of HDMI and USB devices. This external controller allows for many types of applications to be undertaken. For this project, we chose the customized illumination system as the primary application for the controller.

As described above, drones are increasingly used in providing cues to increase situational awareness. It is widely recognized that humans maintain awareness of many aspects of their environment through both selective attention of some features and peripheral awareness of others. Awareness is achieved through

multiple channels simultaneously, most notably visual, auditory, and tactile. In designing a suitable cue we had to consider a typical drone flight. Humans do not directly touch the drone in most interactions so we eliminated that medium. The auditory medium was eliminated as noise from the propeller would overshadow it. Ultimately, we decided to use a visual cue.

We used a WS2815B LED strip to generate our visual cues. WS2815B is a versatile visual enhancement product that has full color-changing capabilities to create plentiful lighting scenes. One of the most appealing features is its individually addressable functionality. The color and brightness of each pixel could be customized by programming to achieve different lighting effects. The placement of the LED strip could be seen in Figure 4.

Power supply: The inclusion of an external control module will introduce another challenge: supplying power. Drawing power directly from the drone's power supply is not wise, as its own power unit has been integrated into the frame. Modifying this module may introduce electromagnetic interference to wireless communication and affect the overall flight control. Therefore, a separate power module needs be to added in the prototype design. Two packs of high capacity 2000 mAh NiMH batteries are utilized as an external power supply module.

Mechanical modifications: One of the core challenges stems from the fact that no mounting devices are built into the drone. A flat "H-Shaped" platform made of carbon fiber is utilized to hold the additional

components. This platform, with the battery pack and the Raspberry Pi onboard computer can be seen in Figure 4.

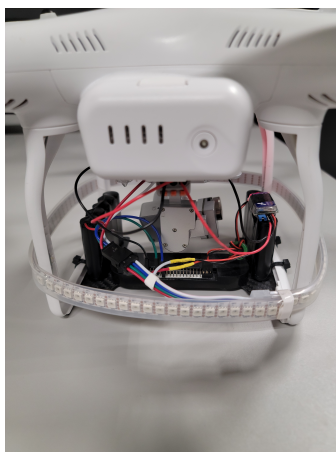


Figure 4. The H-Shaped platform with the External Controller Unit and Power Supply

Drones are not intrinsically stable due to a high aerodynamic sensitivity which is directly impacted by their center of gravity (CoG). In general, a lower CoG aids with the stability of the flight system, but may negatively impact the maneuverability. The changes to the drone cause a slight downward shift in position of the CoG, but it remains within the approximate cylinder formed by the entire frame of the drone. The LED strip unit was fixed on the fuselage in such a manner that will allow the light signal generated from the LED strip to be seen from all directions.

IoT framework: Figure 5 shows an overview of a 4-tier IoT framework in which the present system could be deployed. The potential IoT platform used to deploy the system can be Google Cloud IoT, IBM Watson IoT, Amazon AWS IoT, Microsoft Azure IoT and so on. The Fog layer is an intermediary layer between the edge and cloud layers. The Fog layer would enhance the efficiency by providing computing near the edge computing devices. This type of framework is very suited for geospatial applications, healthcare, smart city, and smart home [21]. The key difference between the two lies in where the location of intelligence and computing power is placed. Fog computing offloads the computation task from the cloud layer down to the local area network (LAN) while edge computing relies more on devices such as embedded automation controllers.

One of the main benefits of using an IoT based illumination system is the ability to use real time data from the cloud to compensate for weather. In

the following, we present a general process of how the drone's illumination system would automatically adjust itself through our IoT platform. For instance, if the system would change the lights automatically based on the current weather condition, the process of its communication to the IoT platform could be summarized as follows (the IoT layers discussed correspond to those appearing in Figure 5.):

- 1) The system will first generate a request and send it to IoT gateways in the edge layer by CoAP/MQTT/AMQP protocol.

- 2) The servers/devices in the edge layer will first process this request in real-time and schedule it either to fog/cloud layer or just execute it in the edge layer, depending on the computing power that the specific request needs.

- 3) Usually, the weather condition web service is one application of Smart City which is deployed in the fog/cloud layer. The servers in the fog/cloud layer process the weather condition request and then responds to the edge layer.

- 4) Finally, the edge server/device schedule to send the result back to the system which would later adjust the illumination based on the weather condition.

Other requirements: Other issues affecting the overall design are security and privacy, which involve the use of new technology and frameworks to ensure the drone and its users are safe and protected. There is also the issue of integrating the drone system to existing infrastructure.

- a) **Security.** As pointed out in [22], drones are nowadays becoming a looming threat since they could conceivably carry weapons or dangerous materials to critical locations. There is also the problem of unauthorized drone operations in restricted or forbidden airspaces. Drones in this case can disrupt military exercises, hospital operations, and even planes. There is also some concern that drones could aid in IT hacking by bringing sensors or disruptive electronics near a possible target.

- b) **Privacy.** One of the more major concerns about drones is the violation of privacy. Drones can enter spaces seemingly undetected and use their mounted cameras take pictures of individuals without their knowledge. They can be used in other illegal activity such as trespassing property and monitoring people without their consent.

- c) **Integration Capability.** The design and development should be easily integrated into existing technol-

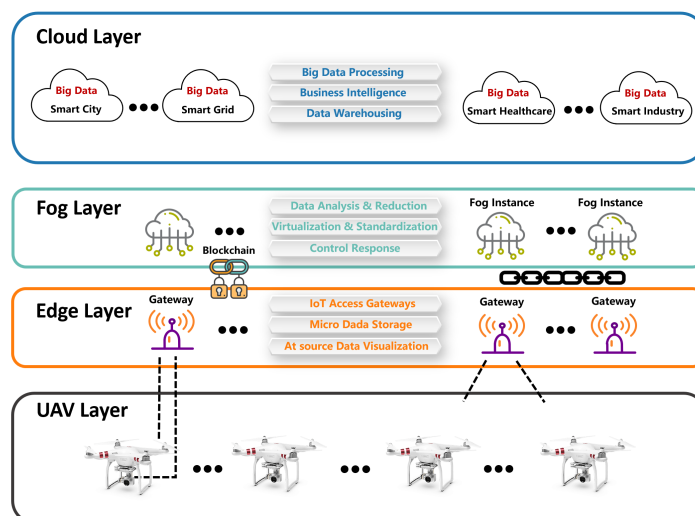


Figure 5. The Different Operational Layers of our System with the Features They Include

ogy and infrastructure. Some of them have comparatively matured and can be directly adopted while others are still in their early stages but still show promise for future development.

Evaluation and Testing

To evaluate the feasibility of our system architecture we conducted two different tests measuring two different aspects, power consumption, and the effect of our application oriented unit on real world scenarios.

Power Consumption Test: As the space for power sources on a consumer level drone is limited, it was important to us to determine how much the battery that supported our application unit would last. We were interested to see how the potential colors and lighting patterns that could be used on a consumer drone affected the overall power consumption. As such we included colors that are commonly used in aviation, such as red, green, white, and blue, and patterns, such as solid, flashing, and revolving.

Our results found that the lighting pattern affected the battery life significantly more than the type of color. To give a frame of reference, we initially tested the total life of the battery pack with nothing enabled, which was 8.4 hours. The solid configuration in comparison averaged at 1.76 hours for all four colors. Among the four, white was the longest lasting with 1.81 and shortest red, with 1.72. In terms of power consumption, the solid pattern consumed almost 5 times the power compared to the stand by mode with an average current of 1138 mA compared to 238 mA.

The second pattern that consumed the most power was the revolving colors pattern with an average current of 913 and a duration of 2.19 hours. The least power consuming pattern was the flashing pattern, with an average of 5.29 hours and 378 mA of overall average current. White and red were the lowest and highest power consuming color types with 5.33 and 5.25 hours respectively, mirroring the results in the solid pattern.

Human-in-the-loop Assessment: The perception of the drone by both drone operators and the people that will be in the vicinity of the drone is critical if drones are to be used in cities and other populated areas. As such, it is important to test the system in the real world environment that it will be deployed in. It is of specific importance to determine how the illumination system would affect the interactions humans have with drones. We chose a task that is very relevant to Human Drone Interaction (HDI): determining the distance of the drone from a specific vantage point.

The experiment was held in an outdoor setting. The protocol was evaluated and approved by the University of Florida IRB board. The vantage point the participants stood made up the center of a circular layout with predetermined points for the drone to hover. There were four such drone hovering points, each located at the cardinal directions. The points on the east and west sides were 5m away, while the points on the north and the south were 6 m away respectively. The two drone configurations were unilluminated and illuminated with white. In total, the participants made 4 guesses and the accuracy was determined by normal-



Figure 6. Experiment Setup for the Human-in-the-loop Assessment

izing the actual distance and the distance participants stated. For this task, the illuminated condition resulted in an error rate of 14.77% whereas the unilluminated condition had an error rate of 22.5% [23]. The distance also had an effect in accuracy, with the error rate increasing from 12.89 to 24.37% percent between 5 to 6 meters. This result shows that there is some benefit to using illumination systems to help observers and drone operators correctly guess the distance of the drone. As many drone operations are conducted within the visual line of sight of the drone operators, increasing the spatial awareness of the drone operator relative to the drone is critical to ensure safe flight. For measuring the effect of color and the existing lighting conditions, we replicated the second task for the red, blue, and white colors and asked which color they preferred the most [20]. We had three categories, clear skies, partially cloudy, and overcast. We observed here that there was some relationship between the weather conditions, more specifically the cloud cover, and the color of the strip. In all partly cloudy and overcast instances the participants preferred the blue color whereas in two out of three instances of clear skies the participants preferred white. In order to understand why they chose the colors they did we asked each participant why they preferred one color over the others. The responses they gave were varied, ranging from the preferred color standing out the most to more unusual ones like aesthetic pleasure and the association with the police. The results from both task one and task two highlight the importance of external factors in HDI and the need to have a customized illumination system that can adapt to weather conditions to increase the drone's visibility.

Another notable study on drone illumination has been done by [24] on using different illumination

Table 1. Color Preferences for the Human-in-the-Loop-Assessment [20]

Participant	Color Choice	Weather	Reason for Choice
P1	Blue	PC	Association with police
P2	Blue	OVC	Aesthetic pleasure
P3	White	CL	Caught the eye most in the sun
P4	White	CL	No real preference
P5	Blue	PC	N/A
P6	White	CL	Stands out from surrounding colors
P7	Blue	CL	Stands out from surrounding colors
P8	Blue	PC	Most comfortable to the eye
P9	Blue	PC	Stands out from surrounding colors

patterns to communicate the direction and planned path of the drone. Their study provides valuable insight on which patterns and placements should be used to make the movements of the drone conspicuous, but there are a few limitations in their study setup. Notably their study was held indoors in a lab setting, which is not the typical operational environment for drones. Secondly, they have used only one color, blue, in their study. As our assessment observed, depending on environmental conditions the color preference may change. Our illumination system and human factors assessment aimed to alleviate these limitations and improve external validity. This assessment did not cover different lighting patterns and their effects on the perception of the drone. In future studies we plan to use our drone system to test different types of drone lighting, especially different lighting patterns.

Limitations and Future Work

Our current prototype has several limitations that need to be addressed before our platform can be deployed reliably. Most of these limitations stem from the fact that the drone is an off-the-shelf product. One of the main limitations of off-the-shelf drones in the proprietary flight software that they come with. The physical component of the drone has requirements the existing software did not allow us to integrate the LED control scheme into the flight software itself, so we had to use another onboard computer, the Raspberry Pi. Although during our human factors assessment portion we did not encounter major problems, EMI interference from additional devices will always be a concern. In future work we will explore more options such as using a more programmable drone. We will also deploy a battery of tests dedicated to testing the reliability of the flight software itself and how flight is affected by it.

Another limitation is the flight time capabilities of the drone. Many consumer level drone such as ours

have flight times that are in the 20-40 minutes range without payload. With payload, these times decrease even further. Increasing this time by adding more power supply on board is very difficult due to the design constraints these drones have, hence carrying spare batteries is almost essential. Even if adding more batteries onboard were possible, this would inevitably affect the flight characteristics of the drone due to added weight. Unfortunately there is no immediate solution to this limitation.

One final limitation concerns our human factors assessment. Although through our human factors assessment we have demonstrated the utility of our LED system and the effects of illumination and color on the perception of the drone, some might argue the tasks of estimating the distance to be simplistic. Additionally, due to the COVID-19 pandemic, we could not reach the participant numbers that are comparable to other HDI studies [24][25].

As drones are proposed to be used in different application areas such as delivery and construction, different types of interactions will arise. In this context in our future studies we would like to investigate how illumination systems could make these interactions more congruent and safe. Whether these interactions are viewed positively by potential users and the general public is also an important element to consider. Additionally, by verifying our results in a future study with a larger sample size and a higher fidelity experiment, we plan to make recommendations in terms of illumination configuration for regulatory agencies and drone manufacturers to use.

CONCLUSION

In this paper we introduce an IoT based drone system that is equipped with a configurable LED illumination system. Firstly, we give a brief overview of existing IoT based drone systems and their functionalities. We then highlighted the need for incorporating safety considerations and discussed the requirements for building a safety conscious IoT based drone. We focused on three categories: the necessary hardware requirements of adding a safety feature to an existing off-the-shelf drone, in our case an configurable LED strip, the power requirements of said LED strip, and the mechanical modifications that need to be done to accommodate these changes. Then we introduce our system architecture and the prototype we built to validate our system. The two tests that we have conducted to evaluate our system, a power consumption

test to see if different colors consume different levels of energy, and a human factors assessment in which we investigated the effect of illumination on the distance perception of the drone were also presented. Finally, we discuss some limitations of our system, mainly stemming from the build of the drone itself

As drones will become more ubiquitous in the near future, ensuring the safety of the drone, their operators, and the general public, will become a major concern for many stakeholders, especially in urban environments. With this study we hope to highlight the importance of illumination in drone safety and provide a framework for how to apply it. However, this study only examines a relatively passive interaction between humans and drone. Real world interactions will be more complex and designing interactions that are appropriate for each scenario is a significant challenge. In future studies we will explore how to utilize our illumination system for HDI in drone applications and settings, such as drone delivery, agriculture, and many more.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation under Award 2024656. The authors would like to thank Nicola Nomura with for her help in proofreading the manuscript and Nil Yerebakan with her help in developing the figures.

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Shuai Hao is currently a 2nd year Ph.D student in the Industrial Systems Engineering Department in the University of Florida. You can contact him here: shuai.h@ufl.edu

Mustafa Ozkan Yerebakan is currently a 2nd year Ph.D student in the Industrial Systems Engineering Department in the University of Florida. You can contact him here: mu.yerebakan@ufl.edu

Boyi Hu is currently an Assistant Professor in the Industrial Systems Engineering Department in the University of Florida. You can contact him here: boyi-ihu@ise.ufl.edu