# EXAMINING THE APPLICABILITY OF SMALL QUADCOPTER DRONE FOR TRAFFIC SURVEILLANCE AND ROADWAY INCIDENT MONITORING

Joyoung Lee, Ph.D.
Assistant Professor
Telephone: (973)-596-2475
jo.y.lee@njit.edu

Zijia Zhong
Telephone: 973-596-8497
Graduate Research Assistant
zz46@njit.edu

Kitae Kim, Ph.D.
Senior Transportation Engineer
Telephone: 973-596-5259
kk64@njit.edu

Branislav Dimitrijevic
Principal Transportation Planner
TEL: 973-596-6463
E-Mail: dimitrijevic@njit.edu

Bo Du
Graduate Research Assistant
TEL: 551-580-6709
E-Mail: bd54@njit.edu

Slobodan Gutesa
Telephone: 973-596-8497
Graduate Research Assistant
sg424@njit.edu

John A. Reif, Jr. Department of Civil and Environmental Engineering
New Jersey Institute of Technology
17 Summit Place, Newark 07102
New Jersey

Corresponding Author: Joyoung Lee

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## ABSTRACT

This paper explores the applicability of small quadcopter drones for traffic surveillance and roadway incident monitoring. Small quadcopter drones have gained significant attention from the public as it is easy to control, safe, economic, and flexible for flight. With two quadcopter drones equipped with video capturing and transmission devices and a ground station, pilot tests have been conducted to examine the effectiveness of quadcopter drones for traffic surveillance and incident monitoring.

Compared to existing traffic data collection practices, quadcopter drones appear highly beneficial as they are capable of covering a wide range of data collection sites, which enables them to capture traffic data of every approach of an intersection at a time. Wide-range visual coverage also facilitates measurements of queue length and delays of intersections. The quality of video footage collected by the quadcopter drone appears challenging for video analytics while it is sufficient enough for manual data collection. In addition, instrumented with a long-range video streaming device, it is able to conduct instant traffic incident monitoring where no traffic surveillance devices are available. Pilot tests clearly demonstrates the quadcopter drone would be suitable for real-time roadway incident monitoring, though up to 20 seconds of communication lag was observed under low cellular signal strength.

## INTRODUCTION

As congestion continues to grow on modern roadway, collecting timely and accurate traffic data is vital in both traffic operations and management. Traditional traffic monitoring is achieved by deploying stationary traffic surveillance devices (e.g., radar sensors, video cameras, inductive loop detectors, etc.) in the transportation network. In particular, traffic surveillance cameras have been widely adopted by transportation agencies for both real-time traffic and incident management. By employing video analytics techniques, traffic surveillance cameras not only collect traffic data (e.g., counts, speed, and occupancy) but also provide live incident scenes to incident management operators. With their advantages, these cameras are still incapable of capturing traffic conditions beyond their range of coverage.

In recent years, small drones have become popular with the advancements of cutting-edge flight control technologies. The latest and the most crucial technologies include 1) GPS-based position hold, 2) long-range wireless video transmission, 3) automatic flight assistance, and 4) fail-safe functionality. Such technologies enable civilian operators to manipulate small drones in an easy and safe manner, thereby resulting in numerous small drone applications on the civilian side. One of the most popular types of small drones would be quadcopter. Equipped with four rotary propellers, quadcopters are capable of not only performing vertical take-off and landing (VTOL), but also hovering in the air.

Small quadcopter drones with their traffic surveillance capability would offer promising potentials to tackle the challenges experienced by stationary traffic surveillance devices. The VTOL capability reduces the time and space for rapid deployment. In addition, with the GPS-based position hold technology and hovering capability, quadcopters would be suitable for instant and flexible traffic surveillance. In this study, we examined the applicability of using small quadcopter drones to capture traffic conditions where no stationary traffic surveillance devices are available. Two pilot tests were conducted for 1) traffic data collection and 2) real-time incident report.

The remainder of the paper is organized as follows. In the next section, general information about small drone is briefly presented along with the latest Federal Aviation Administration (FAA) flight regulations. Relevant efforts in utilizing drones for traffic surveillance and monitoring applications are summarized in literature review section. In the section of case study, the pilot tests are presented in detail. Then the findings and recommendations are addressed in the last section.

## SMALL DRONE

Small quadcopters, as a type of Micro Unmanned Aerial Vehicles (MUAV), are capable of covering a larger area and go beyond the range of existing stationary sensor networks. Due to the unpredictable nature of traffic incidents, the flexibility which MUAVs provides is a perfect complement to the traditional stationary sensor networks. As the flying path is not restrictive to the roadway network and traffic conditions, quadcopters are able to travel at a higher speed than ground vehicles, especially under congested roadway induced by traffic accident. In the event of severe traffic accidents, such less-restricted travel path could be potentially life-saving. In the multiple concurrences of accidents, quadcopter monitoring could provide critical information, helping the fast responders to prioritize the incident treatments and allocate limited emergence resources.

Additionally, quadcopters, as one of the rotary-wind types UAVs, has some advantages compared to fixed-wing UAVs. Quadcopters could fly much closer to the ground: the close-to-ground flying path and the overhead perspective of the quadcopter help police officer to expeditiously document the scene of accident and, as a result, facilitate faster accident clearance. The VTOL capability of quadcopters ensures a minimal launching time and landing space. The hovering capability is one of the most advantageous features and it enables the quadcopter to collect more stable footage for easier traffic data processing.

Despite the promising advantages, it is worth noting the challenges of small quadcopter drones. First their payloads are often limited. Second, the relative light-weight makes them more susceptible to wing and other environmental elements. Third, the small quadcopters usually have limited power supply.  Lastly, there are security restrictions imposed by Federal Aviation Administration (FAA) and Federal Communication Commission (FCC).

As of July 2014 the latest FAA model aircraft regulations are only applicable to aircrafts whose payloads are no more than 55 pounds, unless it’s certified by an aero-modeling community-based organization. The FAA Modernization and Reform Act of 2012(*1*) specifies that prior notice of the flying operation should be provided to airport operator and airport traffic control tower when flying within 5 miles of an airport (*1, 2*). When it comes to allowable ground altitude, Academy of Model Aeronautics national Model Aircraft Safety Code specifies 400 feet within three miles of an airport (*3*).

## LITERATURE REVIEW

Studies have been conducted to examine the advantage of UAVs over manned aircrafts. However, limited research exploiting UAVs for traffic monitoring purposes has been reported. Prior to 2008, UAVs for traffic monitoring attempts were primarily fixed-wing type: they were primarily developed for military usage and then converted to civilian applications, such as performing traffic monitoring. Fixed-wing UAVs have the advantage of high speed, high payload and longer cruising capability.

Airborne Traffic Surveillance System (ATSS), a framework of using drone to obtain traffic information, was proposed by Sirnivasan et al. (*4*). A proof of concept study of the ATSS was subsequently conducted by Florida Department of Transportation (FDOT). In this framework, UAVs were deployed to collect video data and transmit the live data to ground stations along the path of flight.  The live data then was distributed to corresponding traffic management centers where the information would be analyzed for traffic management.  The video transmission was conducted by using FDOT microwave tower system. Simulation-based evaluation results showed that the video data was successfully received at Florida State

Emergency Operation Center. However, no actual flight test was conducted, due to the disapproval of flight plan from FAA. As a result, the research was discontinued in April 2005 (*5*).

Coifman et al. (*6*) proposed four potential applications for fixed-wing UAVs in transportation engineering. The first application was measuring the level of service and AADT of highway by using consecutive still-cut images obtained from UVAs. The authors proposed a mathematical approximation to deal with the lack of hovering capability of fixed-wing UAVs. The second application was collecting the arrival and departure rates of vehicles at signalized intersections to estimate queues and delays. The third application was O-D estimation: to this end, the authors proposed a platoon-based OD estimation method which was only applicable for a small-size network. The forth application is parking lot utilization monitoring.

Ro et al. (*7*) conducted a study on a commercialized small UAV system , namely MLB Bat, for traffic monitoring. It comprises a GPS receiver which guides the autonomous flight, a radio control transmitter, a 2-way data modern for data communication, a laptop as ground control, and a real-time video receiver. A field experiment plan was planned by the authors but no actual fight was conducted due to safety concerns and regulatory issues (*8*).

In 2008, Washington State DOT conducted a study to examine the applicability of UAV as an avalanche control tool. The MLB Bat small UAV system (*7*) as well as a commercial rotary-wing UAV-(i.e.Yamaha R-MAX) (9) were tested. The authors concluded that the strict “see and avoid” rule was still a major obstacle and maintaining routine operation of UAVs would still be a challenge for WSDOT (*9*).

Zhong et al. (*10*) proposed a framework for selecting UAVs for traffic monitoring, by addressing critical factors affecting the performance, such as the type of wings, payload, fight speed, flight time, power source, flight altitude, wind resistance, and cost-effective. Their research provided an informative guideline for selecting UAVs to perform various tasks.

Barfuss et al. (*11*) at Utah Water Research Laboratory have developed an autonomous and multispectral remote sensing platform UAV, named AggieAir. The in-house prototype of AggieAir is a fixed-wing aircraft which utilizes a bungee to launch. In parallel, VTOL UAVs were planned to develop according to the report. Field tests were conducted on a rural highway and on wetlands in Utah. Due to safety concerns, however, the initial plan of flying over highway was suspended.

Hart et al. (*12*) studied the effectiveness and feasibility of using MUAV in performing roadway condition assessment. They used a helicopter-configured UAV due to its high maneuverability, hovering capability, smaller size, and VTOL capability. Wind was found to be the most restrictive weather condition encountered. The MUAV becomes difficult to control under wind speed of 5-10 mph and the operation of the MUAV is significantly interfered when the wind speed reached is over10 mph. In addition, the pilot needs to balance the travel speed and battery usage.

In summary, it was discovered that the majority of the previous research activities relied on full-size UAVs with a fixed-wing configuration for traffic surveillance purposes. While full-size fixed-wing UAV is capable of ensuring longer flight time and handling higher payloads, its maneuverability would be undesirable for traffic surveillance activities which primarily require VTOL, and hovering capabilities. In addition, most of the previous research had not been actually conducted in the field due to safety and regulatory issues. It is noteworthy that those issues encountered by previous research efforts can be resolved by switching to small quadcopter drone. Therefore we focus on the applicability of using small quadcopter drone for traffic surveillance and monitoring.

## CASE STUDY

In this section, we introduce two field deployments to examine the applicability of small quadcopter drone for traffic surveillance and roadway incident monitoring.  The major components of the quadcopter and its supporting devices are presented in the next section, followed by the detailed description of each application.

### Components

#### *Aircraft Unit*

In this research we employed two small quadcopter drones, model name Phantom 2 produced by DJI Corp. (*13*), a manufacturer of small UAVs, as shown in Figure 1(a). Phantom 2 is a low-price and ready-to-fly drone operated by a remote controller. The weight of Phantom 2 is approximately 2 lb, including battery, and its maximum payload is about 3 lb. The stock of 11.1-voltage battery, with a capacity of 5.2 Ampere-Hour (Ah), provides the quadcopter with approximately 20-minute flying time (subjected to environmental elements). The Phantom 2 has a maximum flight speed of 15 m/s, ascending speeds of 6 m/s, and descending speed of 2 m/s, respectively. The drone is controlled by a 5.8 GHz remote controller with a communication distance of up to 0.6 miles in open area. The built-in GPS module enables the aircraft to maintain connection for up to 13 satellites simultaneously for precision flying. When not controlled by the operator, the Phantom 2 hovers in the air by having itself pinpointed by satellites in the airspace. The flying-assistance module is programmed to automatically compensate for winds. The hovering accuracy of the quadcopter is 0.8m in vertical direction and 2.5 m in horizontal direction (*13*, *14*).

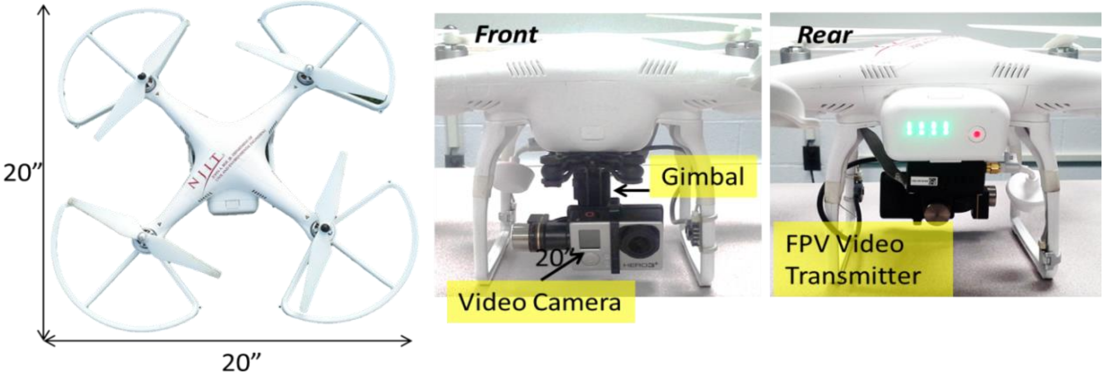
Phantom 2 has several novel operational features making its manipulation safe and convenient. Its fail-safe protocol is the most notable one: once the communication between the aircraft and the remote controller is disrupted or the aircraft flies out of the communication range for more than 20 seconds, the aircraft will automatically return to the initial point where it takes off with the help of a built-in control system and the GPS module. Through the position-hold feature, Phantom 2 is able to maintain a stable hovering position even under wind gusts. The gimbal mounted on the aircraft compensates oscillations and provides stable camera position.

#### *Video Transmission Unit*

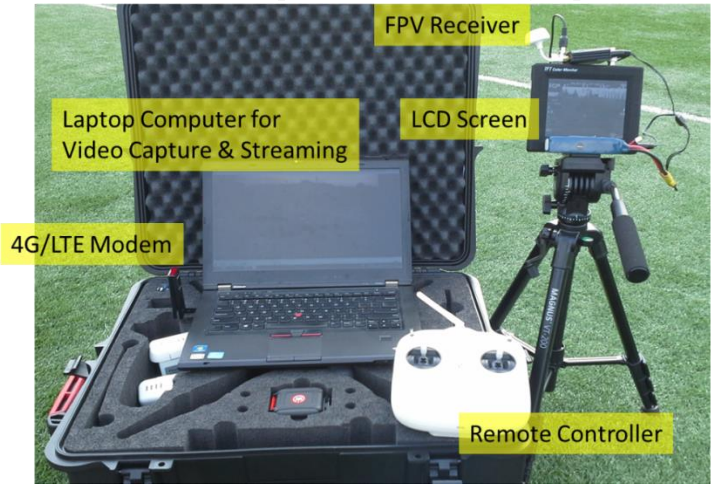
Phantom 2 supports First Person View (FPV) which is a live video image transmission device. Connected to the flight control unit of Phantom 2 and the camera, the FPV device sends video images from the camera with the real-time flight status of the aircraft to a ground station via 2.4GHz wireless communication link for up to 0.6 miles.

### *Ground Station Units*

The ground station unit shown in Figure 1(b) consists of 1) a radio signal receiver for FPV, 2) a video image capture card, 3) a laptop computer with a 4G/LTE modem, 4) an external monitor, and 5) a remote controller.  The laptop computer in the ground station unit is installed with a live video streaming software package to broadcast the video footages captured by the video camera on the quadcopter.



(a) Phantom 2 Specification and major parts

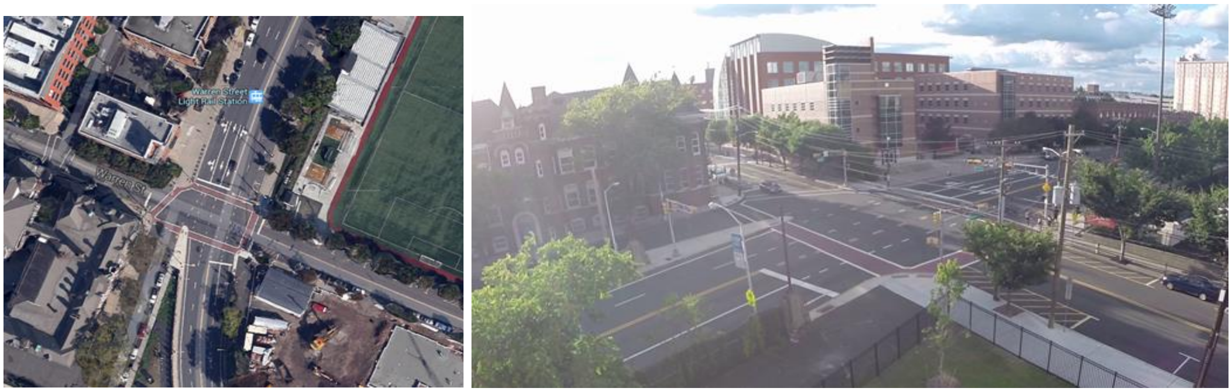


(b) Ground Station

Figure 1 Major Components

## Traffic Surveillance Application

This section deals with two traffic surveillance applications by using the quadcopter drone. The data collection for traffic surveillance was conducted at two intersection sites: 1) Warren Street at Lock Street, Newark, New Jersey and 2) River Road at Hillcrest Drive, Edison, New Jersey. They are shown in Figures 2(a) and (b), respectively.



(a) Site 1 aerial photo (Left) and snapshot (right) captured by quadcopter

(a) Site 2 aerial photo (left) and snapshot (right) captured by quadcopter

Figure 2 Data Collection Sites for Traffic Surveillance Test

In order to examine the impact of altitudes on the quality of the captured video footages for data collection, 10-minute video footages recorded at the altitudes of 45-ft from the site 1 and 90-ft from the site 2 were analyzed. The video footages were also processed through a video analytics program. Table 1 shows the traffic counts obtained from manual counting and the video analytics program. It must be noted that the stability of video footages heavily relies on the wind speed. The video footages collected from the quadcopter may not be perfect for video analytics software that was applied, however it is still identifiable for manual counting.

Table 1 Traffic Volume Counts

| Site | Volume | | |
|---|---|---|---|
| | Manual Count | Video Analytics | Diff (%) |
| Site 1 Northbound (45-ft) | 98 | 37 | 61 (62%) |
| Site 2 Eastbound (90-ft) | 87 | 22 | 65 (74%) |

Besides traffic volume, queue length, delay, headway, and saturation flow rates are crucial measures to determine the performance of an intersection. Collecting those measures from intersections are often challenging due to lack of proper data collection devices and man-power. For example, to capture queue lengths of a certain intersection, the data collection device needs to cover the upstream of an intersection as far as the queues are likely to exist. Therefore it would be challenging within the current data collection practice. Owning to the overhead perspective of the drone FPV, these crucial measures could be collected certainly by manual effort and potentially by stable video analytics software. Table 2 shows the summary of those measures captured at both sites 1 and 2 northbound and eastbound, respectively.

Table 2 Intersection Congestion Measures

| | Site 1 Northbound | Site 2 Eastbound |
|---|---|---|
| Average Queue Length | 64ft (sight restriction) | 104ft |
| Total Delay | 879 seconds (7cycles) | 247 seconds (2cycles) |
| Average Headway | 2.18 second | 2.0 second |
| Saturation Flow Rate | 1,651veh/h/ln | 1,800veh/h/ln |

## Roadway Incident Monitoring

Live video footage of a roadway incident is one of the most crucial information for roadway incident management. Under current practices, live incident video footage is collected by closed-circuit television (CCTV) cameras closely located around the incident scene. Out of the coverage of available CCTVs, it is impossible for a TMC to obtain the video footage of an incident scene. Small quadcopter drone is easy to launch as it requires no dedicated spaces to take off. In that sense, small quadcopter drones would be suitable for rapid deployment to capture video footage of a roadway incident which is out of CCTVs' coverage.

Figure 3 depicts a high-level framework of the proposed quadcopter-based incident monitoring application. Assuming a highway patrol team is equipped with one or two quadcopter drones with a ground station on duty, in case an incident occurs, the patrol team is able to deploy a quadcopter equipped with a FPV to reach the incident scene. The incident video footage captured is transmitted to the ground station through 2.4 GHz radio communications link. With only 0.6 miles communication range of 2.4GHz radio, the FPV transmitter is very unlikely to directly feed the live video footage to a local TMC. To enable a long distance video transmission from the quadcopter, we propose video streaming from the ground unit to a local TMC via a commercial 4G/LTE network as shown in Figure 3.

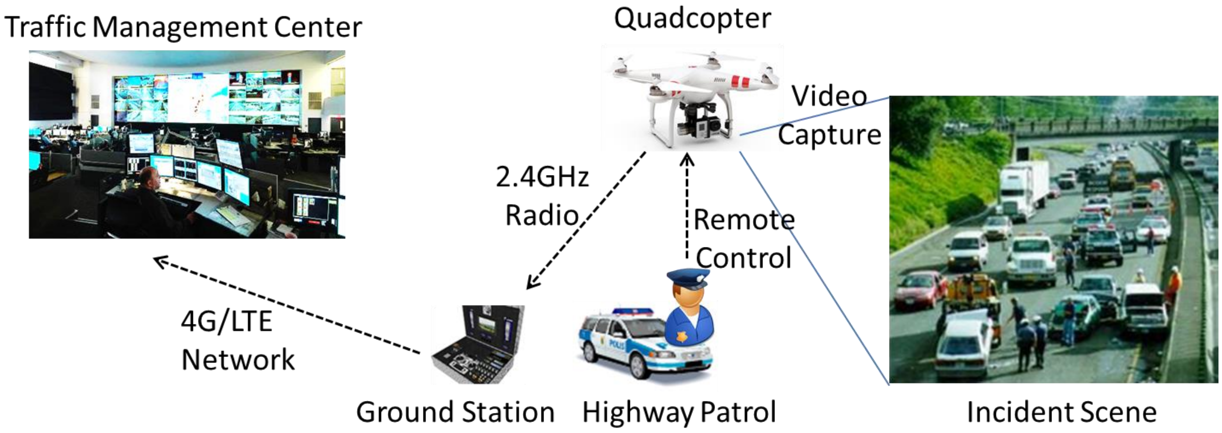


Figure 3 High-level Framework for Quadcopter-based Incident Monitoring

Due to the unpredictability of traffic incidents, two pilot tests were conducted to simulate the roadway incident monitoring application. One is on a freeway segment on interstate highway 80 (I-80) in New Jersey as shown in Figure 3(a). I-80 is one of the major freeways handling heavy daily traffics connecting the east and west sides of New Jersey. Due to its rural location, the 4G/LTE network signal strength appeared to be weak and unstable for live video streaming. The other test site is located on Lock Street in Newark, New Jersey as shown in Figure 4(b). Unlike the I-80 test site, relatively strong 4G/LTE signals were observed during the test. Taking into consideration of one battery supply of a quadcopter, two small quadcopter drones were alternately deployed to seamlessly capture live traffic congestion footages for 30 minutes. The video images captured at the multiple altitudes from 60-ft to 150ft were transmitted to the ground station for an on-line video streaming to the Intelligent Transportations Systems Laboratory (ITSL) at the New Jersey Institute of Technology via Verizon 4G/LTE network service.

(a) Test Site: I-80, Parsippany-Troy Hills, NJ

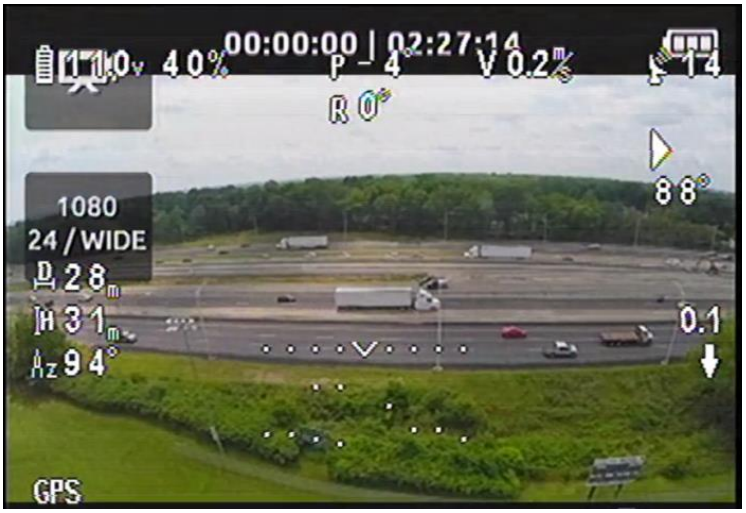
(b) Test Site: Lock Street, Newark, NJ

Figure 4 Test Sites for the Roadway Incident Monitoring Application

The communications lags between the ground station and the ITSL were observed: depending on the signal strength of 4G/LTE network, 3 to 20 seconds of communications delays have been reported. It also appeared that the quality of video footages at the receiving end heavily relies on the signal strength of 4G/LTE. Figure 5 shows the snapshots captured from live video streams from the ground station at the I-80 test site in three different video qualities. In case of a weak signal strength (e.g., one or less signal strength indicator bars), video footages received were unidentifiable as shown in Figure 5(a). Figure 5(b) was captured under median signal strength (2 or 3 bars of signal). Figure 5(c) was obtained while the signal strength was strong (no less than 3 bars). It was also observed that the video quality became unstable while the quadcopter was in motion, particularly in case of 120 ft or a higher altitude. However, when it resumes hovering, stable video images were received.

(a) Low quality video stream (Weak Signal Strength)

(b) Medium quality video stream



(c) High quality video stream (Strong Signal Strength)

Figure 5 Quality of Live Video Stream by 4G/LTE Signal Strength

Table 3 summarizes the durations of low quality video streams which were unusable for identifying traffic conditions (i.e., the case of Figure 5(a)) for both test sites. The low quality time included the total duration of low quality video streams caused by either weak signal strength or movement of the quadcopter drone.  The video footage was still considered acceptable for figuring out the field traffic conditions.

Table 3 Low Quality Video Duration

| Site | Total Streaming Time | Low Quality Time | Low Quality Time Ratio |
|---|---|---|---|
| I-80 Test Site | 557 seconds | 205 seconds | 36.8% |
| Lock Street Test Site | 532 seconds | 48 seconds | 12.8% |

## CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

Rotary-wing small drone UAVs has become popular with the continuous improvement of aircraft control technology including automatic flight control, autonomous navigation, fail-safe, position hold, and vertical take-off and landing (VTOL). These technologies have remarkably reduced the risk of manipulating small drone, thereby resulting in prosperous applications for pastime, business, and research.

The applicability of small quadcopter drone as a traffic surveillance tool has been investigated through multiple pilot tests. The small quadcopter drone adopted in this paper was a low-cost and easy-to-control micro unmanned aerial vehicle which does not require professional knowledge and handful skills of aircraft control.

With a wireless video transmission device equipped on the quadcopter, the video footages captured from the quadcopter camera were seamlessly fed into the ground station for either on- or off-line video analytics. Two case studies conducted to capture traffic data from signalized intersections showed that collecting traffic data through small quadcopter drone is beneficial, as it can cover larger area. Covering larger area enables the drone to capture not only traffic counts but also delay, queue length and saturation flow rate at a time, resulting in costs and effort savings for the data collection. However the stability performance of video footage from the quadcopter may not be high-quality enough for video analytics.

With the enhancement of wireless communications of the ground station by employing commercial 4G/LTE network service and a live video broadcasting software package, the quadcopter drones have been pilot-tested to examine their applicability for on-line roadway incident monitoring. Despite communications delays of up to 20 seconds between the ground station and a remote station located about 16 miles away from the pilot test site; the quality of video footage was considered acceptable incident monitoring.

## Recommendations

Two sets of Phantom 2 small quadcopter drones have been employed to demonstrate their applicability for traffic surveillance and incident monitoring. While Phantom 2 is easy-to-control and small enough to handle, its maximum flight time is about 20 minutes with a video transmission device, a 2-dimensional gimbal, and a HD camera equipped. To overcome the limited flight time, we alternately deployed two quadcopters and they worked well in terms of obtaining continuous video footages. However, such an alternate deployment might be a tiresome task in practice. Thus for an actual field operation, it is recommended to employ long-time flight small drone quadcopters ensuring more than an hour with up to 55 lb payloads.

It was also observed that the stability of video footage from the quadcopter drone is heavily affected by wind, which may result in unacceptable qualify of video image for video analytics. In case of a stronger wind condition, despite the gimbal mounted on the quadcopter to keep the position of camera, the video stability was challenging for video analytics. This issue could be resolved by employing a bigger drone which is less sensitive to the wind and a high precision gimbal unit.

In this paper, live video footages captured from the quadcopter drones were transmitted to a remote station mimicking a TMC through a ground station by using a real-time video streaming program and a commercial 4G/LTE network service. Since such an indirect video streaming would likely result in additional communication delays, it is also recommended to employ direct video streaming equipment to improve the quality of live video images.

## Future Research

Future research opportunities would be addressed to fill out the gaps discovered by the pilot test. First, the quality of video streaming could be improved by employing advanced video processing techniques such as image compression, encoding/decoding, and reproduction. Second, the stability of video image which is one of the critical factors for the implementation of accurate video analytics needs to be improved. Finally, it is worth conducting various tests for potential applications of small quadcopter drones such as transportation infrastructure inspection and data collection for traffic simulation model validation.

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