ITS RESOURCE CENTER

NJIT
New Jersey Institute
of Technology

Activity 2:
ITS Technology Evaluation and Pilot Deployment

Research of UAS Applications
in Traffic Monitoring and Incident Management

Final Report

Prepared for
STATE OF NEW JERSEY
Department of Transportation

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This report has been prepared as part of the CY 2015-2016 work program by the ITS Resource Center at the New Jersey Institute of Technology in collaboration with the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers, the State university of New Jersey.

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Table of Contents

List of Tables

List of Figures

Executive Summary

This report documents the small UAS research that has been conducted by New Jersey Institute of Technology (NJIT) and Rutgers University in research partnership with New Jersey Department of Transportation (NJDOT) and Newark City Traffic Management Center (NTMC). Three major applications were explored: 1) traffic monitoring, 2) traffic incident management, and 3) photogrammetry 3D reconstruction.

A commercial-off-the-shelf unmanned aerial vehicle (UAV) (a.k.a., Drone) was retrofitted with 4G/LET connectivity and a video transcoder for long-distance real-time video streaming. The applicability of small UAV (SUAV) for traffic surveillance and roadway incident monitoring was explored. The research team found that the SUAV is able to cover a wide field of view and is flexible enough for deployment in a variety of data connection sites, compared to existing traffic data collection approaches (e. g. CCTV cameras). Data that is traditionally hard to collect, such as queue length, lane changing patterns etc., can be easily and conveniently captured by the UAV from an overhead perspective.

Live video streaming captured by the onboard camera of the UAV via 4G/LET network has been conducted in a variety of locations in New Jersey, in both rural and urban areas. NJIT partnered with the NTMC to conduct live video streaming to the server at NTMC. The results indicated that an UAS with SUAV is a feasible tool that can be used for rapid deployment for incident monitoring events (e.g. non-recurrent congestion, traffic incident scene). An SUAV is able to provide instant information to the local TMC, which would otherwise not have monitoring access on the scene if camera coverage is lacking. However, the video latency time between an image's capture and display appears to be affected by signal coverage. Under sufficient signal strength, as little as one second of lag time was observed, whereas under poor signal coverage, the video lagged by as much as 20 seconds in some rural areas. A UAV with a bigger payload was tested as well, but it did not outperform the smaller UAVs in terms of traffic incident monitoring application, particularly in cases where a UAS is required to be ready for quick deployment. Overall, the results indicated that SUAVs are easy to control, safe, economic, and flexible for flight and field deployment.

In addition, a multi-functional airborne traffic incident management system (Air-TIMS) was proposed for traffic incident investigation and management using 3-dimension (3D) photogrammetric reconstruction technology. The system is equipped with a high-resolution camera, stabilizing camera gimbal, HD video transmitter, and ground control station. Combined with software such as Mission Planner, Geo-tagging script, and Agisoft Photoscan, the proposed system can be used to reconstruct 3D models of accident sites. The image captured by UAV was analyzed and processed based on correspondence between images with local feature descriptors. Consistency measures such as RAMSAC were utilized to reduce erroneous matching during the process. Twenty-five (25) pictures of a staged accident were taken from different angles by UAV cameras planned through a waypoint plan. Once the pictures were taken and transmitted to the

ground station, the pictures were Geo-tagged using Agisoft. The Geo-tagged pictures were used in Agisoft software to create a correctly scaled 3D model of the accident site.

Lastly, this report briefly summarizes the current Federal Aviation Administration (FAA) regulations with regard to UAV applications and N-number registration. Currently, NJIT, working with NJDOT, has applied for Certifications of Waiver or Authorization (COAs) for UAV deployment and use in an official capacity for NJDOT. However, the lengthy COA approval process under the current regulatory framework was shown to be one of the major roadblocks for UAS implementation. This process is presently being complemented by the newly-release Part 107 regulation by the FAA which is expected to result in modifications that will expedite the process of integrating the SUAV into the national air space (NAS).

1. Introduction

As congestion continues to grow on modern roadways, collecting timely and accurate traffic data is vital in traffic operations and traffic management. The problem of congestion gets exacerbated when traffic incidents occur on roadways that are already suffering from recurring travel delays. The ability to monitor traffic and detect the locations of incidents and traffic congestion as soon as they occur is of great help to transportation system operating agencies, and enables them to respond to any traffic problems more quickly and with adequate resources. Traditional traffic monitoring is achieved by deploying stationary traffic surveillance devices throughout the transportation network, such as video cameras, traffic radars, inductive loop detectors, Bluetooth, WiFi and RFID readers, etc. 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 provide visual awareness of traffic conditions, but can also be used to collect traffic data, such as vehicle counts, speed, and lane occupancy. The problem with the deployment of stationary cameras is that they only provide coverage in their field of view, and it is cost prohibitive to install them everywhere, i.e. cover every mile of roadways in New Jersey, even if this only included freeways and other critical highway facilities.

This deficiency of stationary cameras can be addressed by ad-hoc deployment of SUAV equipped with 'mobile' cameras and appropriate communication systems capable of transmitting video signal in real time. The UAS would be deployed at locations not covered by stationary traffic cameras, and at times of heavy congestion or traffic incidents that cause or are expected to cause significant traffic disruptions.

SUAVs have been used for a variety of purposes, including: law enforcement [1], commodity delivery [2], avalanche monitoring[3], and other civilian applications. Compared to manned aircraft (or more precisely, uninhabited air vehicles), a SUAV is able to maintain a higher fuel to weight ratio due to the lack of weight and volume of not having a human crew and their supporting equipment. SUAVs generally have less capital cost (e.g. manufacture cost) and operational cost (e.g. fuel, crew, maintenance) than manned aircraft. UAVs can fly much closer to the ground than the manned aircrafts. One of the greatest advantages of UAVs is that they can potentially fly in conditions that would be too dangerous for manned aircrafts.

In recent years, SUAVs have become increasingly popular with the added advancements of cutting-edge flight control technologies, even at a consumer grade level. The latest (and the most crucial) technologies include: 1) GPS-based flight positioning, 2) long-range wireless video transmission, 3) automatic flight assistance, and 4) fail-safe functionality. Such technologies enable civilian operators to manipulate SUAVs in an easy and safe manner, thereby resulting in numerous SUAV applications.
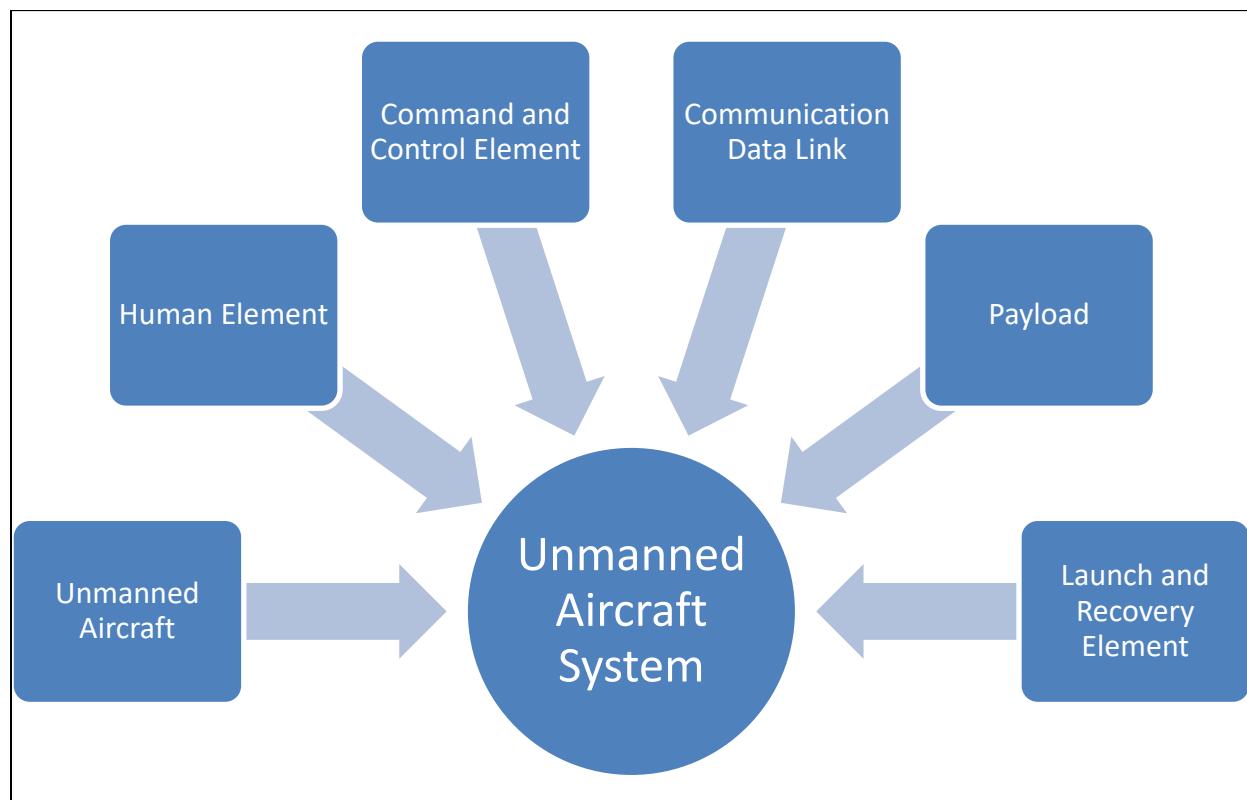
Moreover, an increasing amount of SUAV applications by agencies in the public domain have been reported. For example, SUAVs with traffic surveillance capability would offer a promising potential for tackling the challenges experienced by stationary traffic surveillance devices. The vertical take-off and landing (VTOL) capability reduces the time and space required for rapid deployment. In addition, with the GPS-based position-hold technology and hovering capability, SUAVs would be suitable for swift and adaptable traffic surveillance uses.

2. State-of-the Practice

This chapter covers the reviews of three sections: 1) UAS Platforms, 2) practices using UAS in traffic operation and management, and 3) photogrammetry 3D reconstruction.

2.1. Overview

A typical UAS consists of 6 major components, as shown in **Figure 1**. Except for the UAV, the remaining components could be considered as ground station elements, including a pilot for control, a communication link between the controller and the UAV, and a payload (e.g. sensors, cameras, control receiver etc.) which are all of critical importance in fulfilling the flight missions. A recovery system to stop and retrieve the aircraft may be needed, as shown in **Figure 3**, depending on the UAV configuration, which will be discussed later in this paper.

Figure 1. Composition of an Unmanned Aerial System (UAS)
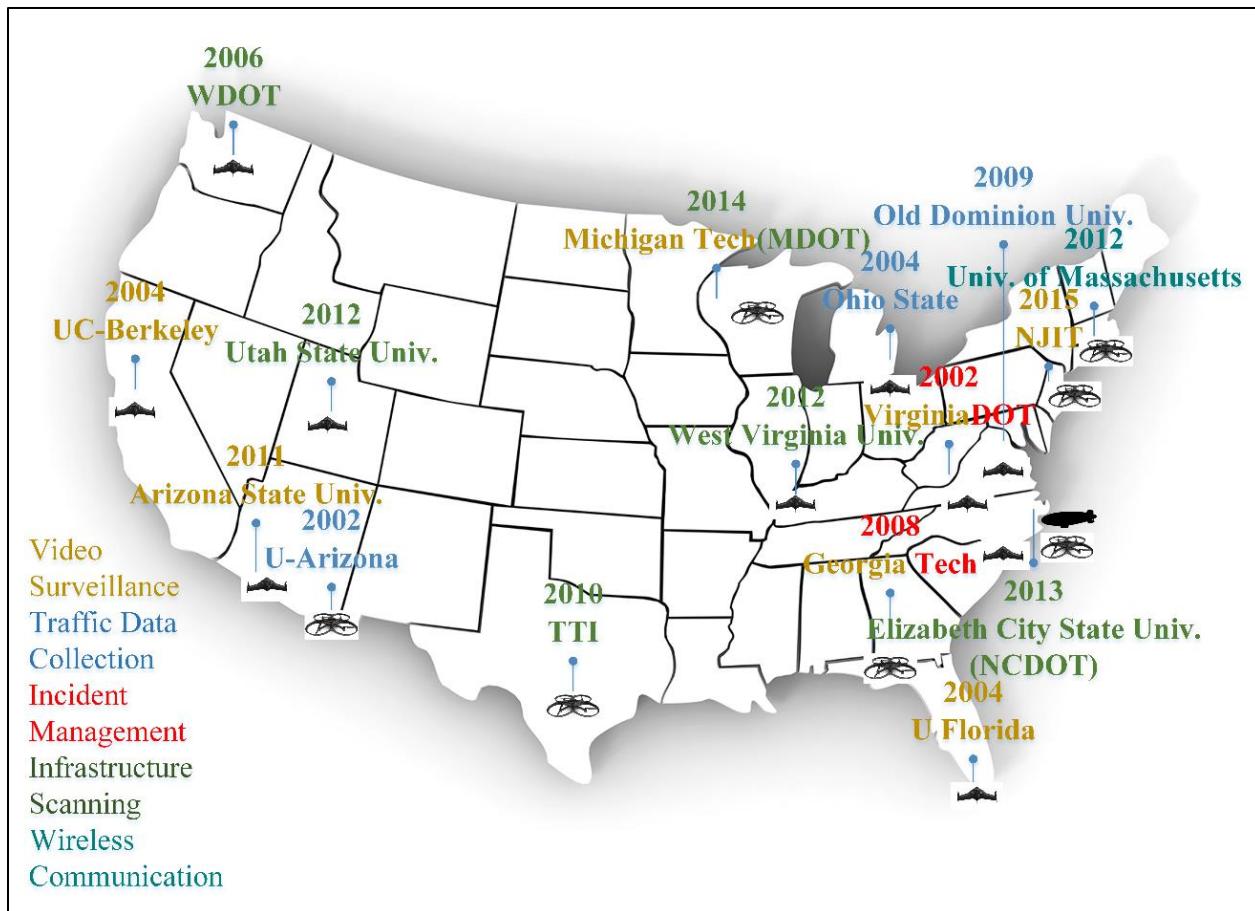
Figure 2. Location of existing UAV studies on transportation infrastructure

The UAV related studies as of 2014 have been summarized in **Figure 2** with color-coded categories (i.e. video surveillance, traffic data collection, incident management, infrastructure scanning and wireless communication.

2.2. UAS Platforms

UAVs can be classified into 2 categories [4] based on an airframe configuration:

▸

▸ Fixed-wing (plane-configured) UAVs

▸ Rotary (helicopter-configured) UAVs

It is true that the aerostat design should also be included in the UAV spectrum. However, this report only discusses UAVs which use active force to maintain airborne capability.

2.2.1. Fixed Wing UAV

Fixed-wing UAVs resemble traditional manned airplanes which are propelled forward by thrust from propellers or jet engines. Because of their long range cruising capability and low profile design, fixed-wing UAVs are primarily developed and adapted for military uses. Cases have been reported where military UAVs (such as the Bat UAV shown in **Figure 3**) were reconfigured for civilian applications (e.g. performing traffic monitoring [5]). Fixed-wing UAVs are able to achieve high cruising speed due to their optimized flight dynamics design. Additionally, they are capable of gliding with minimal fuel consumption, provided certain speed thresholds are met. Because of the fixed-wing configuration, they are also capable of carrying a higher payload, compared to their rotary counterparts. The majority of the fixed-wing UAVs require horizontal take-off and landing (HTOL). Hence, they are likely to require dedicated launching systems for deployment (as well as dedicated systems for UAV recovery (**Figure 3(b)**), which may become an issue for applications that require rapid deployment for traffic engineering applications. Assuming the video footage was captured, a specialized video analytics algorithm is required for post-processing the footage in order to render useful results, due to the machine's constant change of field of view while cruising in the air.

(a)

(Source: Northrop Grumman)

(b)

Figure 3. Fixed-wing UAS (a) and the Recovery System (b)

2.2.2. Rotary UAV

Unlike fixed-wing UAVs, rotary UAVs do not have wings protruding from the body of the aircrafts, and they maintain airborne status by the downward thrust that is generated by the rotors working collaboratively. The relatively traditional rotary UAVs are single-rotor UAV, for instance the Yamaha R-Max shown in **Figure 4**. It is known that single-rotor helicopters are less stable and

more difficult to control in flight. Single rotor UAVs also have more moving parts than quad copters [6], because of the complexities required for maneuvering. Initially, the goal of the multi-rotor design was to remove these complexities [7]. With all rotor blades fixed in pitch under the multi-rotor configuration, the thrust is adjusted by changing the speed of rotation of each rotor. The nose-down and forward movement of a quad-copter, for instance, is achieved by increasing the speeds of the two rear rotors, creating a resulting thrust vector forward; Once the forward flight is established, the rotor speed has to be harmonized by the on-board flight control.

Among all the rotary UAVs, the SUAV type systems are believed to be best-suited for the traffic incident monitoring applications. The concept of the SUAV is defined as a personal-use system that is capable of immediate deployment by one person and is able to be controlled from a mobile ground station. One of the most popular types of SUAV currently in use is the quadcopter machine. Rotary UAVs are not only capable of performing vertical take-offs and landings (VTOL), but they can also hover in the air to maintain a field of view. Even rotary SUAVs are capable of covering a large area and go beyond the range of existing stationary sensor networks. The VTOL capability of quadcopters ensures a minimal launching time and landing space capability. The close-to-the-ground flying path and the overhead visual perspective of the quadcopter helps law enforcement personnel by expeditiously documenting the scene of an accident and, as a result, facilitates faster accident clearance rates.

Figure 4. Yamaha R-Max UAV (source Washington State DOT)

Despite the promising advantages of rotary SUAVs, it is worth knowing the challenges of using rotary SUAVs. First, rotary SUAVs' payloads are often limited to cargoes weighing less than 5

pounds. Second, their lightweight body makes them more susceptible to wind and other environmental elements. Third, the small quadcopters usually have a limited power supply due to their small size and payload limitations.

2.3. UAS Practice in Traffic Operation and Management

In this section, relevant research and deployment concerns with regard to UAS' are discussed. Studies have been conducted to examine the advantages of using UAVs over manned aircrafts. However, limited research utilizing UAVs for traffic monitoring purposes has been reported. Based on the published literature, prior to 2008, UAVs for traffic monitoring attempts were primarily the fixed-wing type.
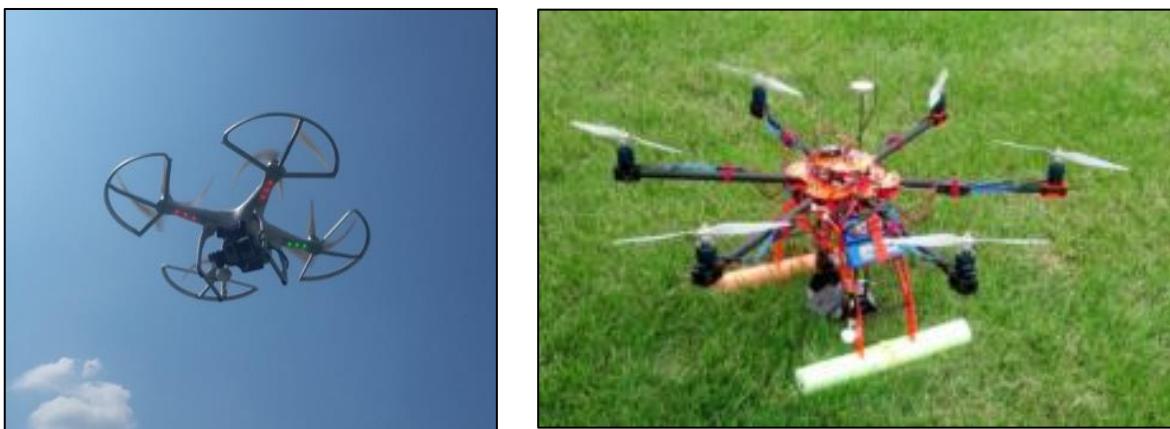
Figure 5. DJI Phantom 2 Quadcopter and Bergen Hexacopter

The Airborne Traffic Surveillance System (ATSS) is a framework for using drones to obtain traffic information, and was first proposed by Srinivasan et al. [8]. A proof of concept study of the ATSS was subsequently conducted by the 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 was then distributed to corresponding traffic management centers where the information would be analyzed for traffic management operations. The video transmission was conducted by using a FDOT microwave tower system. Simulation-based evaluation results showed that the video data was successfully received at FDOT's Emergency Operation Center. However, no actual flight test was conducted, due to the disapproval received from the FAA of a proposed flight plan for the research operations. As a result, the research was discontinued in April 2005 [9].

Coifman *et al.* [10] proposed four potential applications for fixed-wing UAVs in transportation engineering. The first application suggested was for measuring the level of service and AADT of highways 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 for collecting the arrival and departure rates of vehicles at signalized intersections to estimate queues and delays.

The third application was for origin-destination (OD) estimation: to this end, the authors proposed a platoon-based OD estimation method which was only applicable for a small-size network. The last application proposed was for parking lot utilization monitoring. As discussed in the previous section of this report, fixed-wing UAVs have some inherited difficulties in traffic monitoring applications, despite post-processing algorithms that could be implemented to extract data from captured video feeds.

Ro *et al.* [11] conducted a study on a commercialized SUAS system (i.e. MLB Bat) for traffic monitoring. It was comprised of a GPS receiver which guides the autonomous flight, a radio control transmitter, a 2-way data modem for data communications, 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 [12].

In 2008, Washington State DOT researchers conducted a study to examine the applicability of UAS as an avalanche control tool. The MLB Bat SUAS system [7] as well as a commercial rotary UAS (i.e. the Yamaha R-MAX) [3] were tested. The authors concluded that the strict "see and avoid" rule required by the FAA was still a major obstacle and maintaining routine operation of UAVs would yet be a challenge for WSDOT [3].

Zhong *et al.* [13] proposed a framework for selecting UAVs for traffic monitoring, by addressing critical factors affecting the performance, such as wing configuration, payload, flight speed, flight time, power source, flight altitude, wind resistance, and cost-effectiveness. Their research provided an informative guideline for selecting UASs to perform various tasks.

Barfuss *et al.* [14] at Utah Water Research Laboratory 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 cord to launch. Additionally, VTOL UAVs were planned to deploy for monitoring as well, according to the report. Field tests were conducted on rural wetlands in Utah. Due to safety concerns, however, the initial plan of flying over highways was suspended.

Hart *et al.* [4] studied the effectiveness and feasibility of using SUAVs in performing roadway conditions assessments. They used a rotary UAV because of its high maneuverability, hovering capability, smaller size, and VTOL capability. Wind was found to be the most restrictive weather conditions encountered. The SUAV becomes difficult to control under wind speeds of 5-10 mph; furthermore, the operation of the SUAV experiences significant interference when the wind speed reaches over10 mph. In addition, the pilot needs to balance the travel speed and the battery usage.

The Minnesota Department of Transportation (MNDOT) has deployed a quadcopter (model: Aeyron Skyranger UAV) for bridge inspections research [15]. Four bridges in the State of Minnesota were chosen for the comparative tests. The researchers deployed the UAV to see if it could identify the issues which had been previously detected by traditional manual inspections. Results show that the drone footage was able to identify most of the issues discovered during visual inspections. The UAS could not identify the maintenance issues under the deck of the bridges, due to FAA regulations which do not allow UAVs to fly under the bridge deck without a COA. This report stated that none of the applications for COAs had been approved in time for the actual field assignments, and such delays could make using UAS for inspections cost-prohibitive as a tool.

Michigan Department of Transportation (MIDOT) in partnership with MichiganTech Research Institute (MTRI) demonstrated the use of various UAV technologies in helping MIDOT evaluate and manage its resources cost-effectively. Six types of rotary UAVs: Bergen hexacopter, DJI Phantom 2, Blackout Mini H Quadcopter, FPV factory Mariner Quadcopter, Walkera QR 100S, and Heli-Max 1 Si were tested [15]. The tested sites were diverse in nature as well, and included 2 bridges, 2 pump stations, 2 traffic sites and a roadway asset site. The distinctive deployments for MIDOT were in confined spaces (e.g. a pump station, a culvert). The experiments proved that UAS technology can help provide visual inspections from an overhead perspective for various transportation infrastructures in an inexpensive manner.

It was noticed that before 2008, most of the UAS used for traffic monitoring or bridge inspection were equipped with fixed-wing UAVs, most of which were initially designed for military applications. With the advancement of flight technologies, both consumer grade and professional grade SUAVs have been introduced to the civilian market, significantly increasing the accessibility while keeping the cost driven down. While a full-size fixed-wing UAV is capable of ensuring a longer flight time and handling of higher payloads, its maneuverability would be undesirable for traffic surveillance activities which primarily require VTOL and hovering capabilities. When it comes to field deployment tests, several references mentioned that the delay of getting COA from the FAA was a major regulatory obstacle, and is a main factor in the suspension of many proposed field tests and deployments. The FAA regulations are briefly discussed in the following section.

2.4. Photogrammetric 3D Reconstruction

3D reconstruction from images is a classic computer vision problem that has been studied extensively for a few decades. The early focus in the field was on recovering 3D geometry from images with known camera poses. A rising research interest in this field is running 3D reconstruction at large scales on images with unknown camera poses, in particular, those images harvested from different sources on the Internet. Furukawa et al.[16] described the basic technical ingredients for this type of research as: 1) matching algorithms for providing accurate correspondence; 2) SFM algorithms for estimating precise camera pose using the matched feature; and 3) multi-view-stereo (MVS) methods for taking images with pose as input and producing dense 3D point clouds. Indeed, these elements have become standard components in

many types of open source or proprietary 3D reconstruction pipelines, such as Autodesk 123D Catch, VisualSFM, Photosynth, PhotoModeler, and openMVG. In general, these pipelines start with detecting a correspondence between images with local feature descriptors such as SIFT, Harris Corner, and SURF. During this step, certain consistency measures such as RANSAC are often introduced to reduce erroneous matches. SFM-based pose estimation is then conducted to estimate camera poses. Notable SFM methods include the multi-frame SFM[17-19] and the now widely used bundle adjustment[20]. Once the camera poses are solved, MVS methods are launched for dense reconstruction. The most common MVS method is the Patch-based Multi-View Stereo (PMVS) [7].

3. FAA Regulation Review

The conventional FAA regulation for manned aircraft and the latest Part 107 UAS regulation are discussed in this section.

3.1. Overview
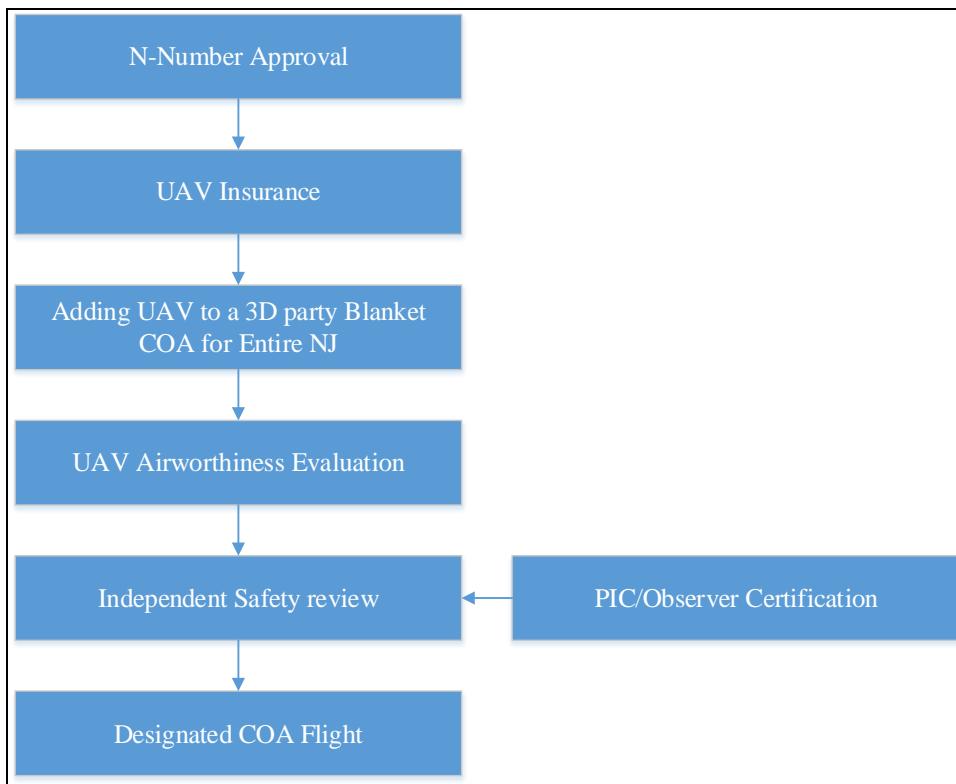
The FAA Modernization and Reform Act of 2012 [21] specifies that prior notice of UAV flight operations should be provided to airport operators and airport traffic control towers when flying within 5 miles of an airport [21, 22]. When it comes to allowable ground altitude, the Academy of Model Aeronautics National Model Aircraft Safety Code specifies a flight restriction of 400 feet within three miles of an airport [23]. However, heights of 250 feet are capable of providing useful aerial imagery in practical tests [6]. As of July 2014, the latest FAA model aircraft regulations are only applicable to aircrafts whose payloads are no more than 55lbs, unless the aircraft is certified by an aero-modeling community-based organization. For UAVs that are heavier than 55lbs, a traditional COA is required prior to flight. Under FAA Section 333 exemptions, a Blanket COA can be granted by the FAA for flights which are below 200ft for a SUAV (less than 55lbs) under Visual Flight Rules (VFR)[24]. A COA is required, however, once the UAV is operated outside of the criteria of the blanket COA.

Starting in Dec. 2015, the FAA implemented new requirements for UAS registration, which now mandates that the owner of any SUAS weighing more than 0.55lbs and less than 55lbs must register their SUAVs online. For aircraft weighting more than 55lbs, the traditional FAA aircraft registry is applied [25]. For non-hobby activity, a COA [26] issued by the Air Traffic Organization to a public operator for a specific unmanned aviation activity is required. At the FAA's discretion in terms of operational and technical review, provision or limitations may be imposed as part of the COA approval to ensure the safety of operations with other airspace users. Some research considered current FAA rules (as of 2015) as onerous for requiring COA applications for bridge inspections and the associated delays incurred for obtaining the approvals are significant. However, the FAA is expected to amend the current regulatory framework regarding SUAVs by removing many obstacles pertaining to regulatory requirements in the near future [15].

3.2. Certificate of Wavier or Authorization

After a complete application is submitted for COA, the FAA conducts a comprehensive operational and technical review. If necessary, provisions or limitations may be imposed as part of the approval to ensure the UA can operate safely with other airspace users. In most cases, the FAA

will provide a formal response within 60 days from the time a completed application is submitted. **Figure 6** shows the steps to obtain a designated COA.

Figure 6. COA Process

3.2.1. N-number

First step in the process of obtaining the COA is the N-number registration. N-Number is a unique number which will be assigned to UAVs for Identification. The flowchart shown in **Figure 7** depicts the process of obtaining an N-Number.

The first step is to identify the UAV university owner or representative by submitting the 8050-1 and 8050-2 forms to the FAA. Form 8050-1 is the aircraft registration application and form 8050-2 is the aircraft bill of sale. Form 8050-88 needs to be submitted online. The next step is to submit the sales and delivery receipts to the company where the UAV was bought to inquire about the N-Number Non-registration. N-Number Non-registration shows that the UAV has not been registered anywhere else. Once the three forms and N-number non-registration has been submitted, the FAA evaluates the application. The N-number will be issued if the application is approved by the FAA. If the UAV cannot comply with aircraft marking standards per 45.21 and 45.23 through 45.33, N- number size marking waiver should be requested. An example of proposed marking on such UAV is shown in **Figure 8** (Rutgers' Quad-X multirotor UAV): proposed using 1" letters (Arial Bold) located on top of the protection panel as depicted.
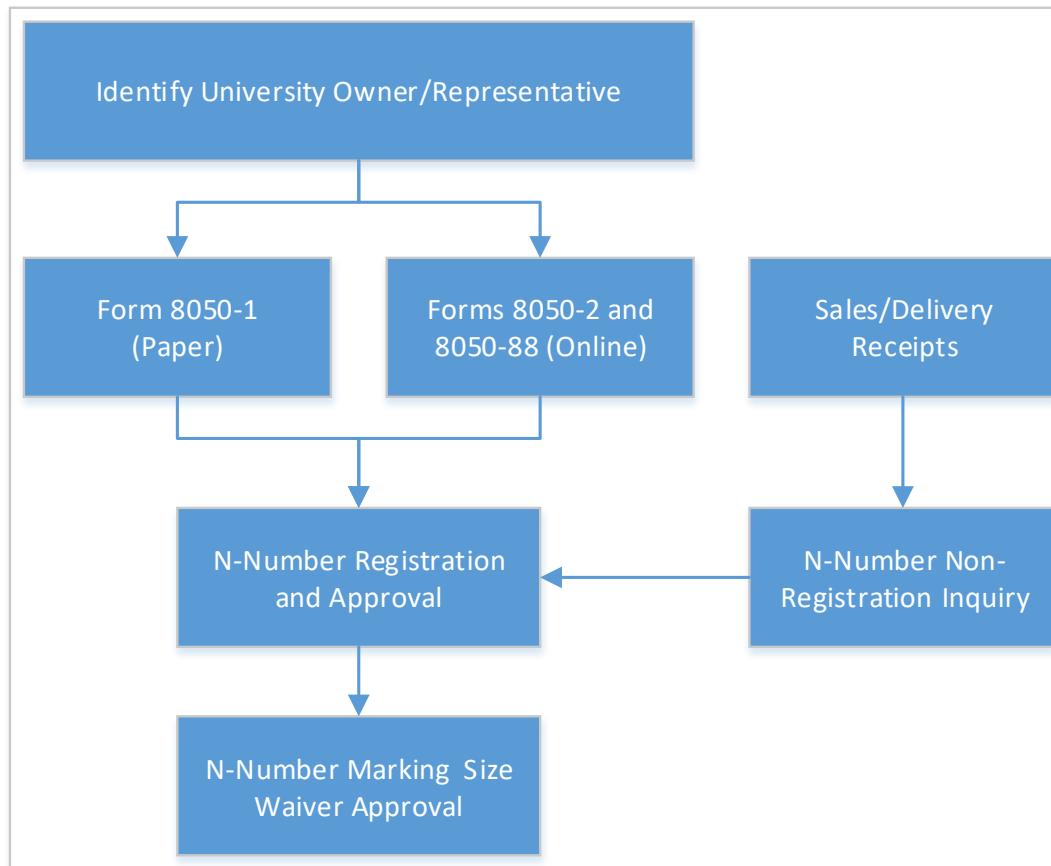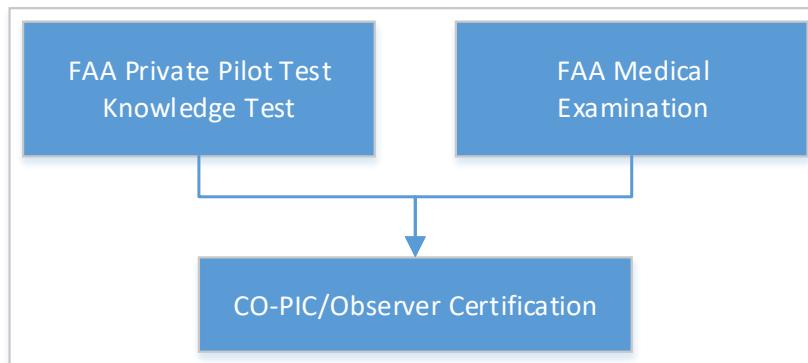
Figure 7. N-Number Registration Process

Figure 8. N-number marking example with a size waiver

3.2.2. PIC/Observer Certification

FAA requires the UAS to have at least two crew members, one pilot in command (PIC) and one observer. Both the PIC and the observer should be certified by passing the private pilot knowledge test and the 3rd class medical certification. The FAA private pilot test contains 60 questions. The applicant should obtain a score of more than 70 percent to pass the exam. The exams can be taken online at designated locations approved by the FAA. After passing the private pilot test, the applicant is required to be examined for and to obtain Type A/B medical certification by an approved designated Doctor, shown in **Figure 9**. The certification shows that the pilot has the physical ability to perform a flight.

Figure 9. PIC/Observer Certificates

3.2.3. UAV Insurance

The UAV has to be insured for liability. The insurance is required in order to obtain the designated COA. The insurance will include the coverage for equipment damages, primarily for the Drone itself and its on-board payload, and the liability coverage for property damages and injuries occurring during operation incidents.

3.2.4. Blanket COA

The next step is to add the UAV to a blanket COA or a COA application thorough section 333. Under the new policy, the FAA will grant a Certificate of Waiver or Authorization (COA) for flights at or below 200 feet to any UAS operator with a Section 333 exemption for aircraft that weigh less than 55 pounds, operates during daytime Visual Flight Rules (VFR) conditions, operates within the visual line of sight (VLOS) of the pilots, and stay at certain distances away from airports or heliports:

▶ 5 nautical miles (NM) from an airport having an operational control tower; or

▶ 3 NM from an airport with a published instrument flight procedure, but not an operational tower; or

▶ 2 NM from an airport without a published instrument flight procedure or an operational tower; or

▶ 2 NM from a heliport with a published instrument flight procedure

The "blanket" 200-foot COA allows flights anywhere in the country except in restricted airspace and other areas, such as major cities, where the FAA prohibits UAS operations. Previously, an operator had to apply for and receive a COA for a particular block of airspace, a process that can take 60 days. The agency expects the new policy will allow companies and individuals who want to use UAS within these limitations to start flying much more quickly than before.

3.2.5. UAV Airworthiness

The next step is to obtain the UAV airworthiness from the FAA. Consistent with applicable Aircraft Certification Service (AIR) policies and instructions, FAA manufacturing ASIs are authorized to issue experimental certificates and special flight permits covered in this order. For the purposes of this directive, FAA manufacturing ASIs are responsible for the issuance of both original and recurrent experimental certificates and special flight permits to UASs, OPAs, and OPA/UASs.

3.2.6. Independent Safety Review Board (ISRB)

In the last step of obtaining the Designated COA, ISRB will join the UAV crew for a demo Flight under the Blanket COA. All the required documents and the Flight will be evaluated by the ISRB. Once the ISRB approves the Documents, the designated COA can be obtained.

3.3. SUAS Part 107 Process

The new rules for non-hobbyist small unmanned aircraft (UAS) operations Part 107 of the Federal Aviation Regulations [17].This section presents the summary of Part 107.

3.3.1. Operating Requirements

The small UAS operator manipulating the controls of a drone should always avoid manned aircraft and never operate in a careless or reckless manner. The UAS must be kept within the line of sight of the pilot. Alternatively, if a First Person View or similar technology is being used, a visual observer must accompany the pilot to always keep the aircraft within unaided sight (for example, no binoculars). Neither the pilot nor a visual observer can be responsible for more than one unmanned aircraft operation at a time. Flights can be performed in daylight or in twilight (30

minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting. Minimum weather visibility is three miles from the control station. The maximum allowable altitude is 400 feet above the ground, and higher if the drone remains within 400 feet of a structure. The maximum speed is 100 mph (87 knots). The small UAS can't be flown over anyone who is not directly participating in the operation, not under a covered structure, or not inside a covered stationary vehicle. No operations from a moving vehicle are allowed unless the UAS is flying over a sparsely populated area. Operations in Class G airspace are allowed without air traffic control permission. Operations in Class B, C, D and E airspace need ATC approval. An external load can be carried on the UAS if it is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft. Systems, payload and cargo should weigh less than 55 pounds in total.

3.3.2. Pilot Certification

To operate the controls of a small UAS under Part 107, a remote pilot airman certificate with a small UAS rating is required, or the operator must be under the direct supervision of a person who holds such a certificate.

To become a pilot:

- Be at least 16 years old

- Be able to read, speak, write, and understand English (exceptions may be made if the person is unable to meet one of these requirements for a medical reason, such as hearing impairment)

- Be in a physical and mental condition to safely operate a small UAS

- Pass the initial aeronautical knowledge exam at an FAA-approved knowledge testing center

Application Process:

- An appointment with a Knowledge Testing Center (KTC) must be scheduled, at one which administers initial and recurrent FAA knowledge exams

- The initial aeronautical knowledge test must be passed

- FAA Form 8710-13 for a remote pilot certificate (FAA Airman Certificate and/or Rating Application) must be completed using the electronic FAA Integrated Airman Certificate and/or Rating Application system (IACRA)*

- A confirmation email will be sent when an applicant has completed the TSA (Transportation Security Administration) security background check. This email will provide instructions for printing a copy of the temporary remote pilot certificate from IACRA.

▶ A permanent remote pilot certificate will be sent via mail once all other FAA-internal processing is complete. @Blackfin109 @jw33062

3.3.3. UAS Certification

The operator is responsible for ensuring the UAS is safe before flying, but the FAA does not require small UAS to comply with current agency airworthiness standards or obtain aircraft certification. Instead, the remote pilot will simply have to perform a preflight visual and operational check of the small UAS to ensure that safety-pertinent systems are functioning properly. This includes checking the communications link between the control station and the UAS.

3.3.4. Respecting Privacy

Although the new rule does not specifically deal with privacy issues in the use of UAS, and the FAA does not regulate how UAS gather data on people or property, the FAA is acting to address privacy considerations in this area. The FAA strongly encourages all UAS pilots to check local and state laws before gathering information through remote sensing technology or photography. As part of a privacy education campaign, the agency will provide all drone users with recommended privacy guidelines as part of the UAS registration process and through the FAA's B4UFly mobile app. The FAA also will educate all commercial drone pilots on privacy during their pilot certification process; and will issue new guidance to local and state governments on UAS privacy issues.

3.3.5. Other Requirements

In addition to above rules, the pilot in command has to comply with several other provisions of the rule:

▶ The UAS must be available to the FAA for inspection or testing upon request

▶ A report must be reported to the FAA within 10 days of any operation that results in serious injury, loss of consciousness, or property damage (to property other than the UAS) of at least $500.

3.4. Comparison between Flights under Part 107 and COA Process

The major difference in part 107 and an ordinary COA is the requirement to obtain the waiver. The requirements for part 107 are considerably reduced. For part 107 the pilot is only required to pass the airman knowledge test and register the UAS. Whereas, the COA requires the pilot to pass the medical test, insure the UAS, obtain the airworthiness verification and ISRB

(Independent Safety Review Boar) evaluation in addition to part 107 to receive the COA. In terms of the flying condition both 107 and COA requires the UAS to be 400 feet above the ground and 400 feet away from the structure. The UAS can't fly over people, who are not directly associated with the activity in part 107, whereas, in COA the UAS can't fly over a populated area. The minimum visibility for flight operation in both waivers is three miles. Operations in Class G airspace are allowed in part 107 without air traffic control permission. Operations in Class B, C, D and E airspace need ATC approval.

4. UAS Overview

This chapter presents the overview of UASs utilized for the applications conducted by the NJIT and the Rutgers research teams. The NJIT UAS has been deployed for the applications of traffic data surveillance and traffic incident monitoring and management that will be discussed in Section 4.1 and 4.2.

4.1. NJIT UAS

The UAS in use by NJIT is the DJI Phantom 4, which is a commercial-off-the-shelf UAS retrofitted with real-time LTE-based video streaming components.

4.1.1. Aircraft Unit

In this research we employed two small quadcopter SUAVs, model name Phantom 2, that were produced by DJI Corporation [27], a manufacturer of SUAVs, as shown in **Figure 10**. Phantom 2 is a low-priced and ready-to-fly SUAV operated by a remote controller. The weight of the Phantom 2 is approximately 2 lbs., including battery, and its maximum payload is about 3 lbs. The stock of an 11.1-voltage battery, with a capacity of 5.2 Ampere-Hour (Ah), provides the quadcopter with approximately 20-minutes of 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 speeds of 2 m/s, respectively. The SUAV 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 no control inputs are actuated, the Phantom 2 is able to be pinpointed in the airspace by satellites. The flying-assistance module is programmed to automatically compensate for winds. The hovering accuracy of the quadcopter is 0.8 m in a vertical direction and 2.5 m in a horizontal direction [27, 28].

DJI Phantom 2 has several novel operational features making its manipulation safe and convenient. Its return-home (a type of fail-safe) protocol is the most notable element: once the communication between the aircraft and the remote controller is disrupted or once the aircraft flies out of the communication range for more than 20 seconds, the aircraft will automatically execute the protocol by returning to the initial point where it took off with the help of a built-in control system with the GPS module. The gimbal mounted on the aircraft compensates for oscillations and provides stable camera positions and it can compensate for wind gusts up to a certain degree.
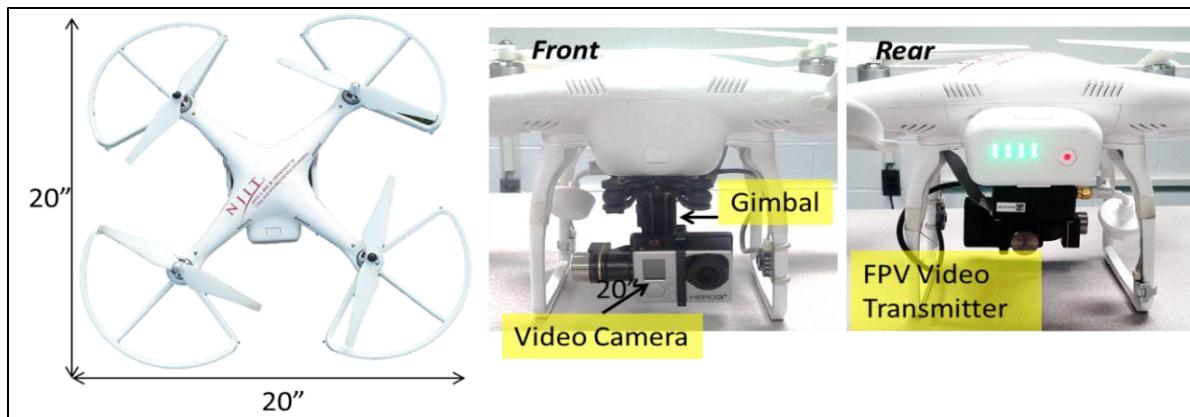
Figure 10. DJI Phantom 2 dimensions, front and rear view
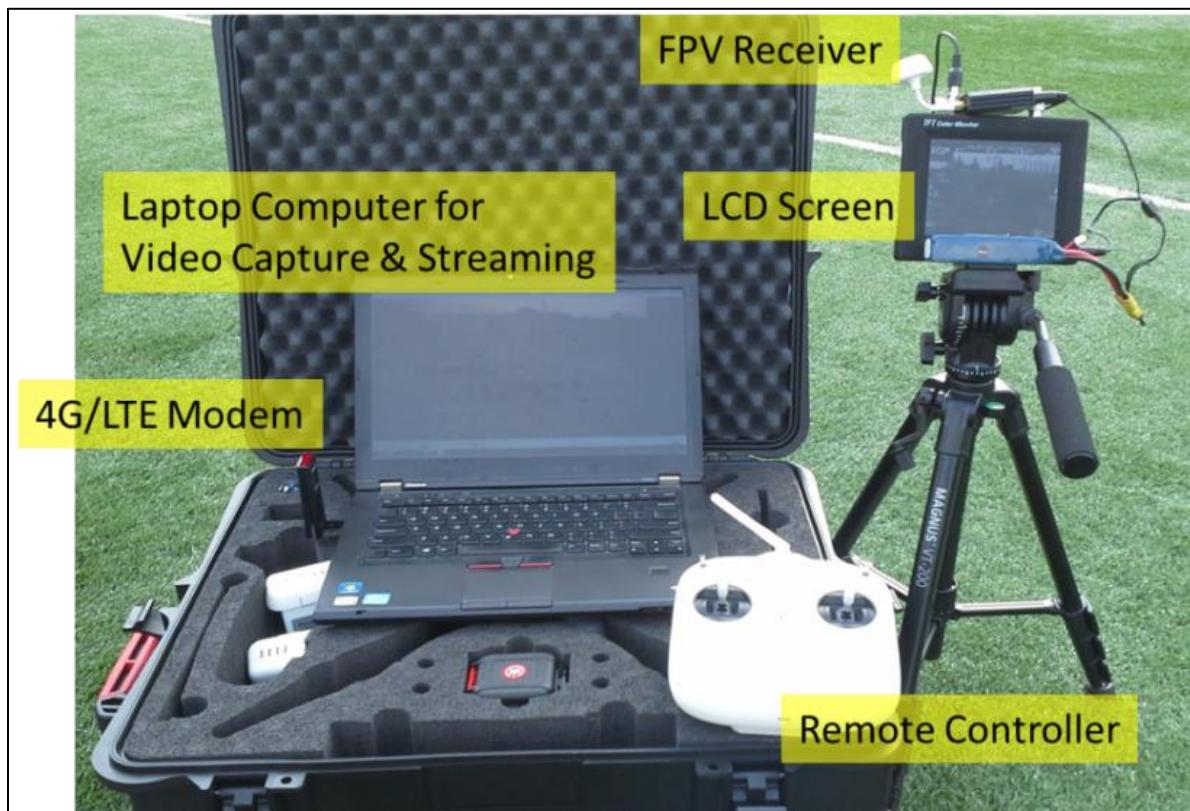
Figure 11. Ground station for DJI Phantom 2

4.1.2. Video Transmission Unit

Phantom 2 also supports First Person View (FPV), which is a live video image transmission. Connected to the flight control unit of the 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, and it does so via a 2.4GHz wireless communication link that has a range of up to 0.6 miles.

4.1.3. Ground Station Unit
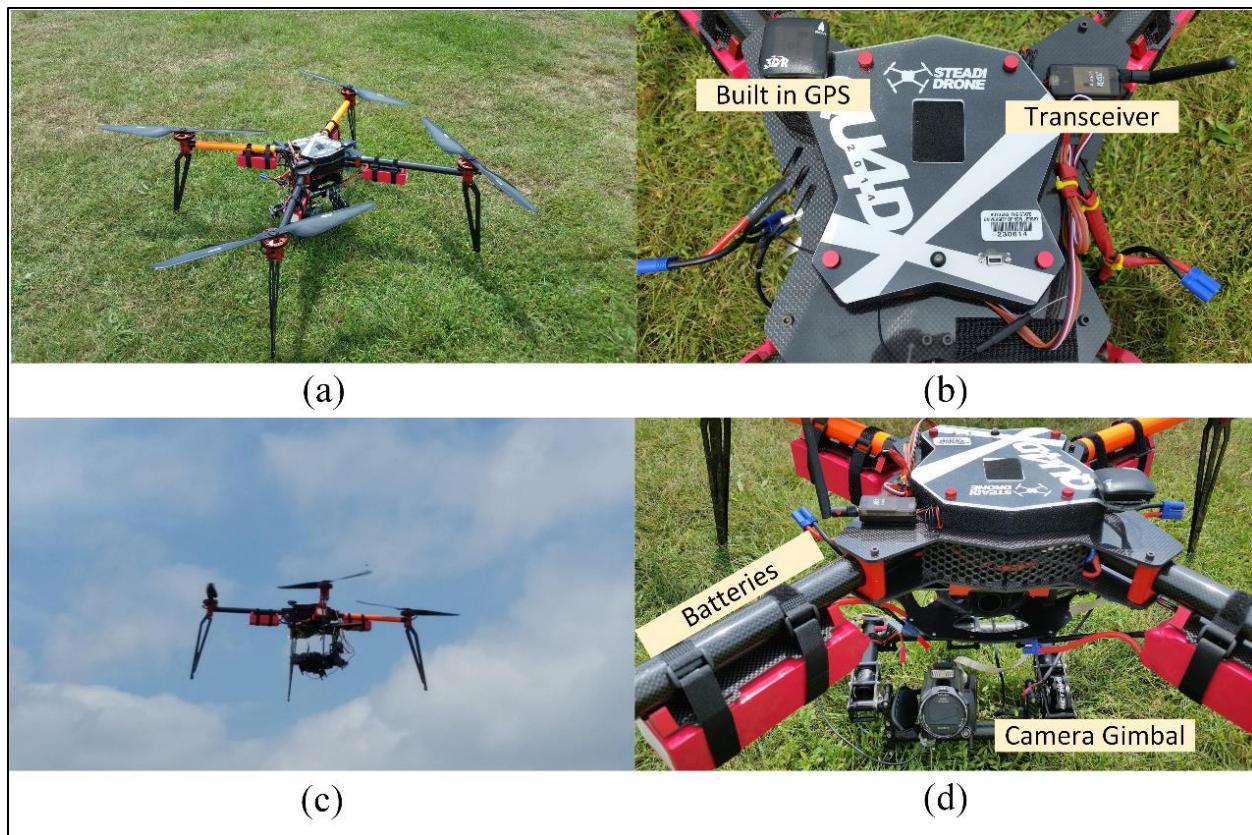
The ground station unit shown in **Figure 11** consists of: 1) a radio signal receiver for FPV, 2) a video image capture card, 3) a laptop computer with a 4G/LTE modem, 4) an external monitor, and 5) a remote controller. The video is captured in the ground station laptop, and is then broadcast by Real Time Streaming Protocol (RTSP) protocol, which can be accessed by using the static pubic IP assigned to the ground station.

4.2. Rutgers UAS

The system is a prototype multi-functional airborne traffic incident management system (Air-TIMS) for investigation, management, and coordination during traffic incidents. The system was designed with an idea of developing an economically justifiable case for the use of UAVs in traffic management. The Air-TIMS system consists of four major hardware components: Aircraft unit, Camera and Gimbal Control, HD Transmitter and Receiver, and Ground Control Station.

4.2.1. Aircraft Unit

In this study we acquired a mid-size quadcopter UAV, called QU4DX produced by STEDIUAV Company as shown in **Figure 12**. The UAV is designed with long propellers enabling it for higher payloads, as well as making the UAV more stable for video recording and image capturing. The UAV payloads is 20 pounds, consisting of the camera gimbal, the camera, theHD transmitter and the UAV power source including four 10000 mAh batteries. Batteries are two-by-two in parallel providing 20000 mAh capacity for 20 to 30 minutes of flight time in full payload condition. The UAV is controlled by a 2.4 GHz controller with a communication range of 2km. The UAV is equipped with GPS enabling it to communicate with available GPS satellites for precise flight. This UAV platform has the capability of performing a full automatic flight plan using the built in GPS and Mission Planner Software [29]. The flight plan can be developed in the software using the GPS coordinates of desired locations for photography including latitude, longitude, and altitude and can be uploaded to the UAV for automatic flight including the landing. UAV Flight mode can be switched between auto mode and manual during the flight with a click of a switch. The switch will assist the pilot to put the UAV in manual mode when the UAV is not performing properly. The UAV communicates with the ground station via 915 MHz transceiver to send the real-time status of a flight to the Mission Planner software. The UAV is equipped with a transceiver enabling the UAV to send flight status information to the ground station for monitoring and receiving the flight plan for performing the auto flight.

(a) UAV (b) built-in GPS and transceiver (c) UAV during flight (d) batteries and camera gimbal

Figure 12. UAV Aircraft unit owned by Rutgers University

4.2.2. Camera and Gimbal Control

The camera gimbal was built in a way to stabilize the camera in both roll and pitch axis using the electronic stabilizers for better video and image recording as it shown in **Figure 13**. The camera gimbal can be either controlled manually via wireless communication for changing the pitch and roll angle (camera angle) or automatically with the UAV using the flight plan. The yaw dimension unit was removed to save the payload and increase the stability of the platform. The camera used in this study is SONY HXR-NX30U[30] which has the capability of HD video recording, image shooting, wireless control communication, built-in GPS, and lens stabilizer. The wire communication control includes zooming and recording and image shooting. Both camera and gimbal can be controlled using the 2.4 GHZ controller.

4.2.3. HD Transceiver and Ground Station

The HD transmitter and receiver was used in this study is the Paralinx Tomahawk [31]. It has the ability to transmit HD video via 5.8 GHZ communication link up to 800 meters. Ground station units shown in **Figure 13** includes the following: 1) laptop, 2) USB transceiver, 3) HD receiver

and external monitor, 4) video image capture card, and 5) UAV and camera controllers. Mission planner was installed on the laptop for flight status monitoring, flight planning development and uploading the flight plan on the UAV using the transceiver on the UAV and laptop.

Figure 13. QU4DX UAS Components: (a) camera gimbal, and (b) ground station

4.2.4. Software Component

The software components of Air-TIMS for accident site reconstruction functionality include 1) mission planning, 2) Geo-tagging and referencing, 3) photogrammetric 3D reconstruction software, and 4) LiDAR scanning.

▶ **Mission Planning Software:** The open-source Mission Planner (Version 1.3.30) Software is used for monitoring the UAV status, compass calibration, waypoint planning for autonomous flight missions, and planning the positions and angles of photo or video shooting positions and angles.

▶ **Image Processing and Geo-Tagging Script**: A hybrid Matlab-Java program is developed to process photo and video footage from the UAV flight and to match photos or snapshots with UAV flight records which contain detailed 3D geographic location information. In the case study, since photos are taken based on the pre-planned waypoints, Geo-tagging can be automatic within the 3D reconstruction software.

▶ **Photogrammetric 3D Reconstruction Software:** Agisoft Photoscan is used to conduct the photogrammetric 3D reconstruction from accident site photographs. The key inputs for Agisoft include the photos or video snapshots with significant overlaps between consecutive images (e.g. 70% or more), Geo-coordination of photos, ground control points and their pixel location in each photograph. Either Geo-tags or a ground control point is needed to ensure that the scale of the 3D model is fixed to the actual dimensions. The ground control points are needed to accurately calibrate the geo-positions of the accident sites with respect to earth coordinates.

5. Proof-of-Concept Tests for UAS Applications

In this chapter, we introduce 3 field deployments to examine the applicability of SUAVs for traffic surveillance and roadway incident monitoring.

5.1. Traffic Surveillance

This section deals with two traffic surveillance application studies conducted using the Phantom quadcopter SUAV. 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. These sites are shown in **Figure 14**.
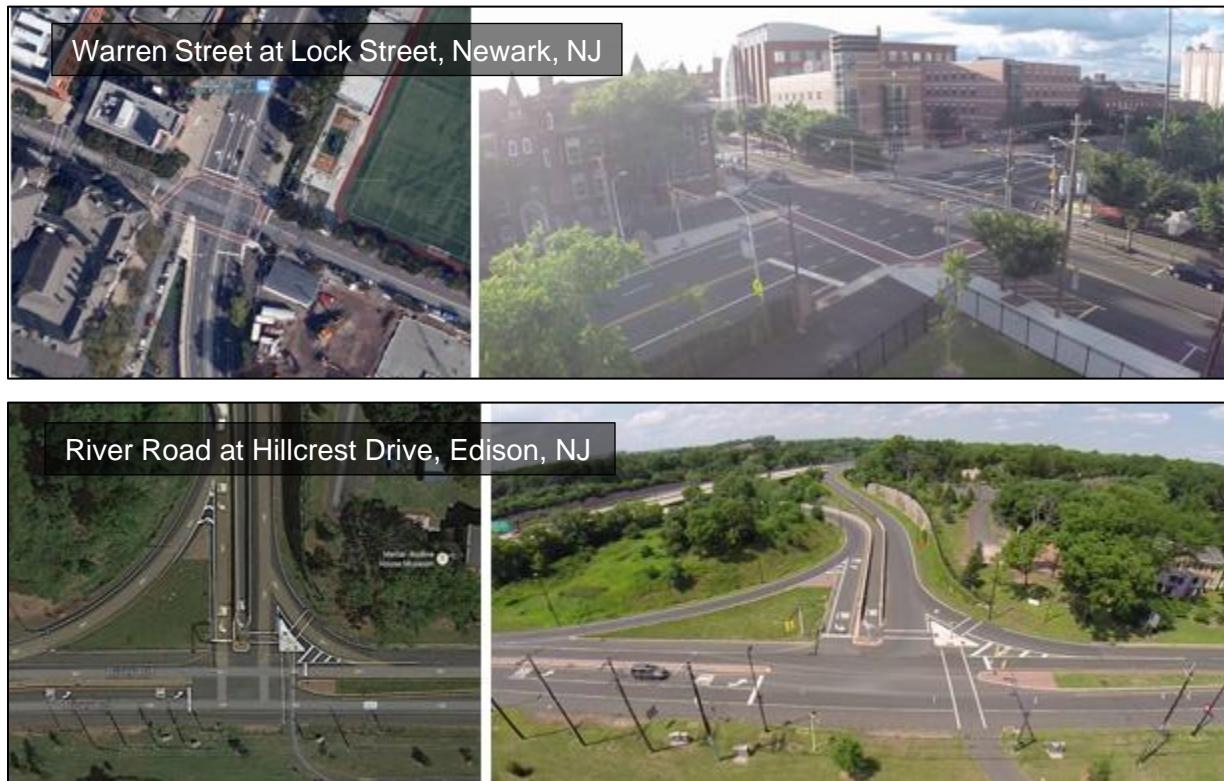

Figure 14. Data Collection Sites for Traffic Surveillance Test: Aerial photos (left) and photos captured from the UAS (right)

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

Table 1. Traffic Volume Counts

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

Besides the traffic volume, other crucial measures that are used for determining the performance of an intersection include queue length, delay, headway, and saturation flow rates.   Collecting those measures from intersections is often challenging due to the lack of proper data collection devices and man-power. For example, to capture the queue lengths of a certain intersection, the data collection device needs to cover the upstream of the intersection as far as the queues are likely to exist. Therefore, it would be challenging within the current data collection practice to accomplish this task. Owning to the overhead perspective of the SUAV FPV, these crucial measures could certainly be collected by manual effort and potentially by a 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

Performance Measure	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

5.2. Roadway Incident Monitoring

The concept of roadway incident monitoring along with proof-of-concept test are presented in this section.

5.2.1. Benefits of Using Small UAS for Traffic Incident Management

The first and most immediate benefit of utilizing small UAS for incident management is situational awareness. In the proposed concept, the video signal would be streamed in real time from the camera on-board the UAS to the Traffic Management Center (TMC). This concept is illustrated in **Figure 15**.

Figure 15. Concept of UAS deployment for Traffic Incident Management (TIM)

At the TMC, the traffic operators would be able to view the conditions at the incident scene in real time, as opposed to receiving verbal reports from the ground via radio communication. The ability to fly the UAS upstream of the traffic incident location and a 360° viewing angle also provides additional flexibility in assessing the impact of the incident on traffic, such as queue build-up and queue length. This includes the ability of timely detection of secondary incidents upstream and a prompt response to these incidents and other potentially hazardous situations caused by improper driver behavior. The birds-eye view of the incident scene also allows for better situational awareness, as opposed to relying solely on the from-the-ground view. UAS can also be used in an incident investigation: it can be used to take high-definition images of the incident scene from multiple angles more quickly, thus helping to open the roadway to traffic sooner.

A study[1] of UAS use for applications in transportation conducted by the Michigan Department of Transportation (MDOT) resulted in an action plan matrix that guided executives in applying changes in department policies and current practices. Following recommendations from the study, MDOT worked with local and state police agencies to demonstrate the use of UAS for crash scene investigation and responses to traffic incidents using UAS. This demonstration indicated that UAS technology can successfully be used for traffic incidents.

5.2.2. Field Tests

Live video footage of a roadway incident is one of the most crucial pieces of information for roadway incident management. Under current practices, live incident video footage is collected by closed-circuit television (CCTV) cameras that are closely located around the incident scene. From the areas covered by the available CCTVs, it is impossible for any TMC to obtain all of the needed video footage of an incident scene. An SUAV is easy to launch as it requires no dedicated spaces to take off. In that sense, a SUAV would be a suitable option for rapid deployment to capture video footage of a roadway incident which is out of range of the CCTVs' coverage area.

Figure 15 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 SUAVs 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 a 2.4 GHz radio communications link. With only 0.6 miles of communication range of a 2.4GHz radio, the FPV transmitter is extremely 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.

Due to the unpredictability of forecasting traffic incidents, two pilot tests were conducted to simulate the roadway incident monitoring application. One is on a freeway segment on the Interstate highway 80 (I-80) in New Jersey as shown in **Figure 16**. 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 16**. Unlike the I-80 test site, relatively strong 4G/LTE signals were observed during the test at this site. Taking into consideration the time limitations of a one battery supply for a quadcopter, two small quadcopter SUAVs were alternately deployed to seamlessly capture live traffic congestion footages for 30 minutes. The video images captured at multiple altitudes from 60ft to 150ft were transmitted to the ground station via on-line video streaming to the Intelligent

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1 "Evaluating the Use of Unmanned Aerial Vehicles for Transportation Purposes", Michigan Technological University and the Michigan Department of Transportation, 2015.

Transportations Systems Laboratory (ITSL) at the New Jersey Institute of Technology using Verizon's 4G/LTE network service.
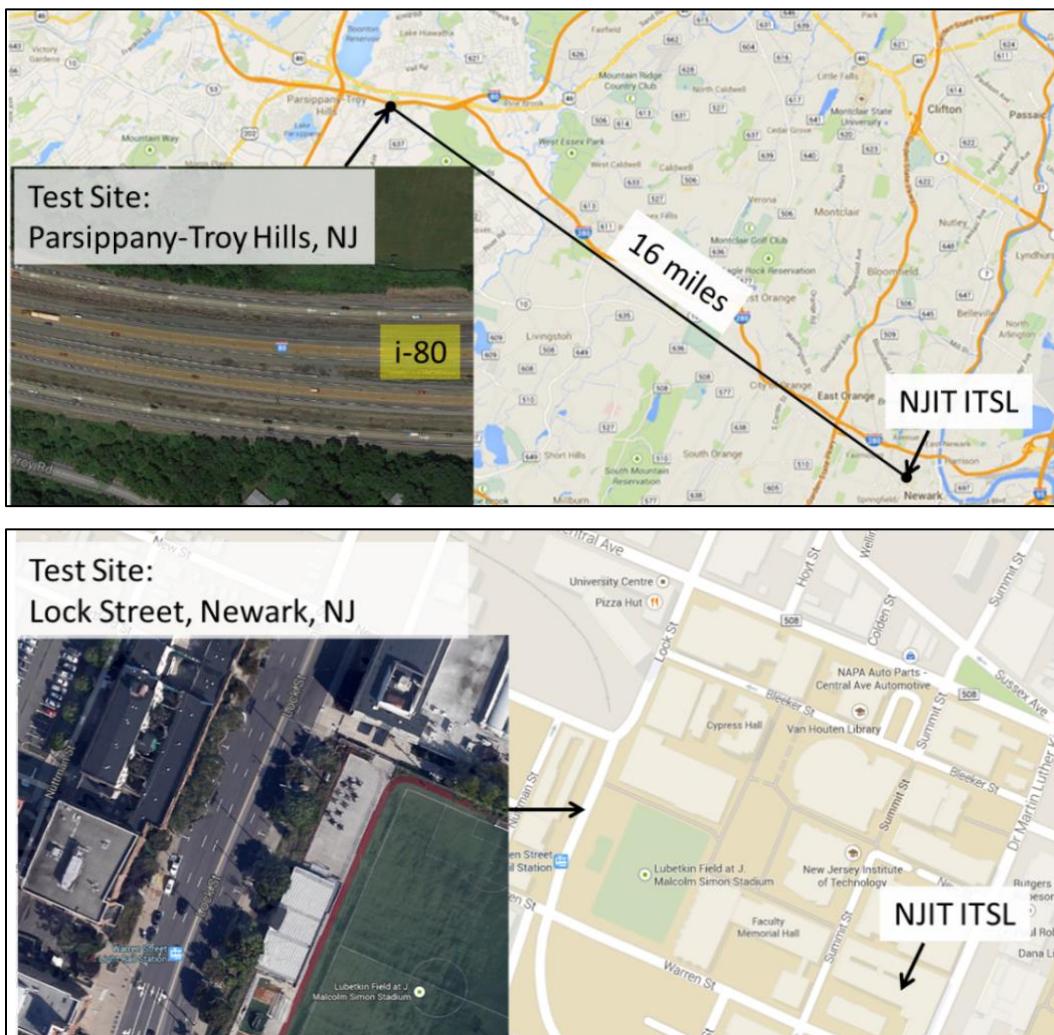
Figure 16. Test Sites for the Roadway Incident Monitoring Application

Communications lags between the ground station and the ITSL were observed: depending on the signal strength of the 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 4G/LTE signal strength. **Figure 17** shows the snapshots captured from live video streams from the ground station at the I-80 test site in three different video qualities. In cases of a weak signal strength (e.g., one or less signal strength indicator bars), the video footage received was unidentifiable, as shown in **Figure 17** (top). **Figure 17** (middle) was captured under median signal strength (2 or 3 bars of signal). **Figure 17** (bottom) was obtained with a relatively high signal strength (no less than 3 bars). It was also observed that the video quality became unstable while the quadcopter was in motion, particularly at the altitude of 120 ft or higher. However, when the machine resumes hovering, stable video images were received.

Low quality video streaming (Weak Signal Strength)

Medium quality video streaming

High quality video streaming
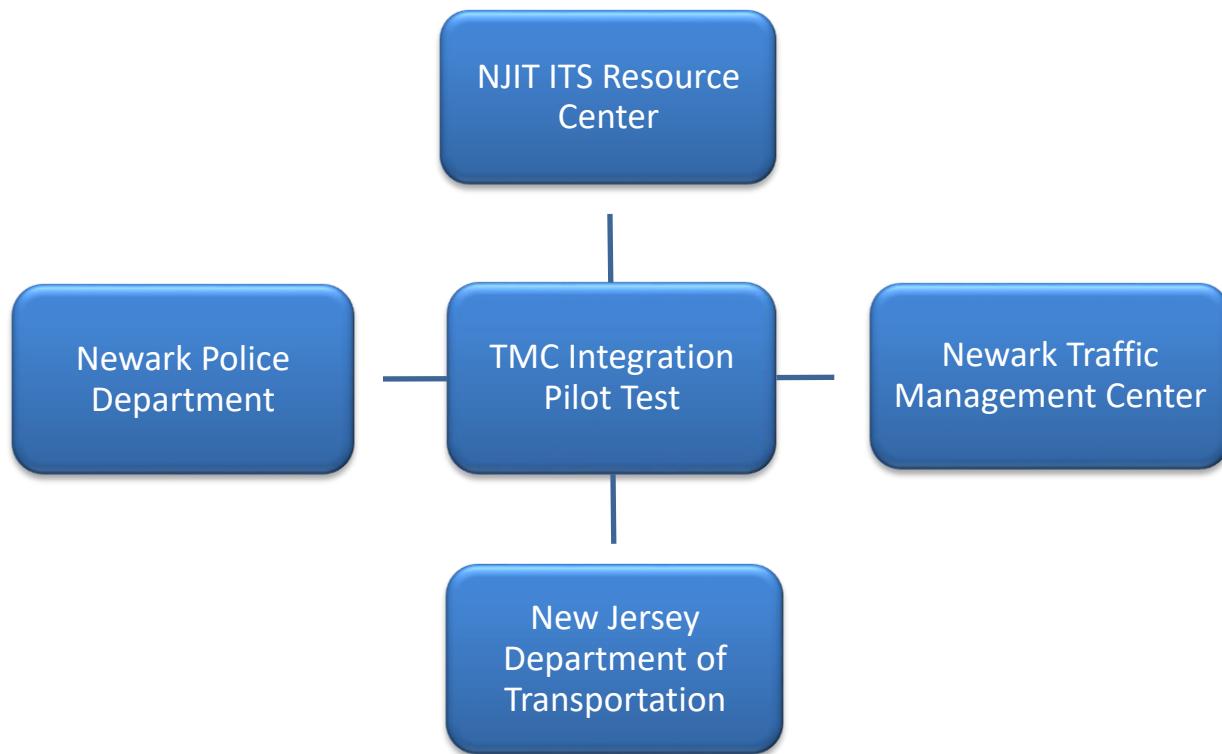
Figure 17. Quality of Live Video Streaming by 4G/LTE Signal Strength

Table 3 summarizes the durations of low quality video streams, which were unusable for identifying traffic conditions (i.e., the case of low quality video streaming (weak signal strength), as shown in **Figure 17** (top)) 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 SUAV. 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 Ratio
I-80 Test Site	557 seconds	205 seconds	36.8%
Lock Street Test Site	532 seconds	48 seconds	12.8%

In partnership with City of Newark, NJIT conducted a further test for the feasibility of live-streaming video directly to the city's traffic management center (TMC) as conceptually depicted in **Figure 18**. The Real Time Streaming Protocol (RTSP) was used for the live-video streaming with assistance from an open source software-VLC player. After securing the perimeter with the help of Newark's Police Department for a safety demonstration, the quadcopter SUAV flew up to 10ft ground altitude and then hovered in the air to capture the intersection movements.

Figure 18. TMC Integration Pilot Test Partnership

	(a) Screenshot of High-definition Video Captured by On-board Camera
	(b) Screenshot of Flight Control Status on Ground Station
	(c) Screenshot of Real-time Video Feed Received in NTMC
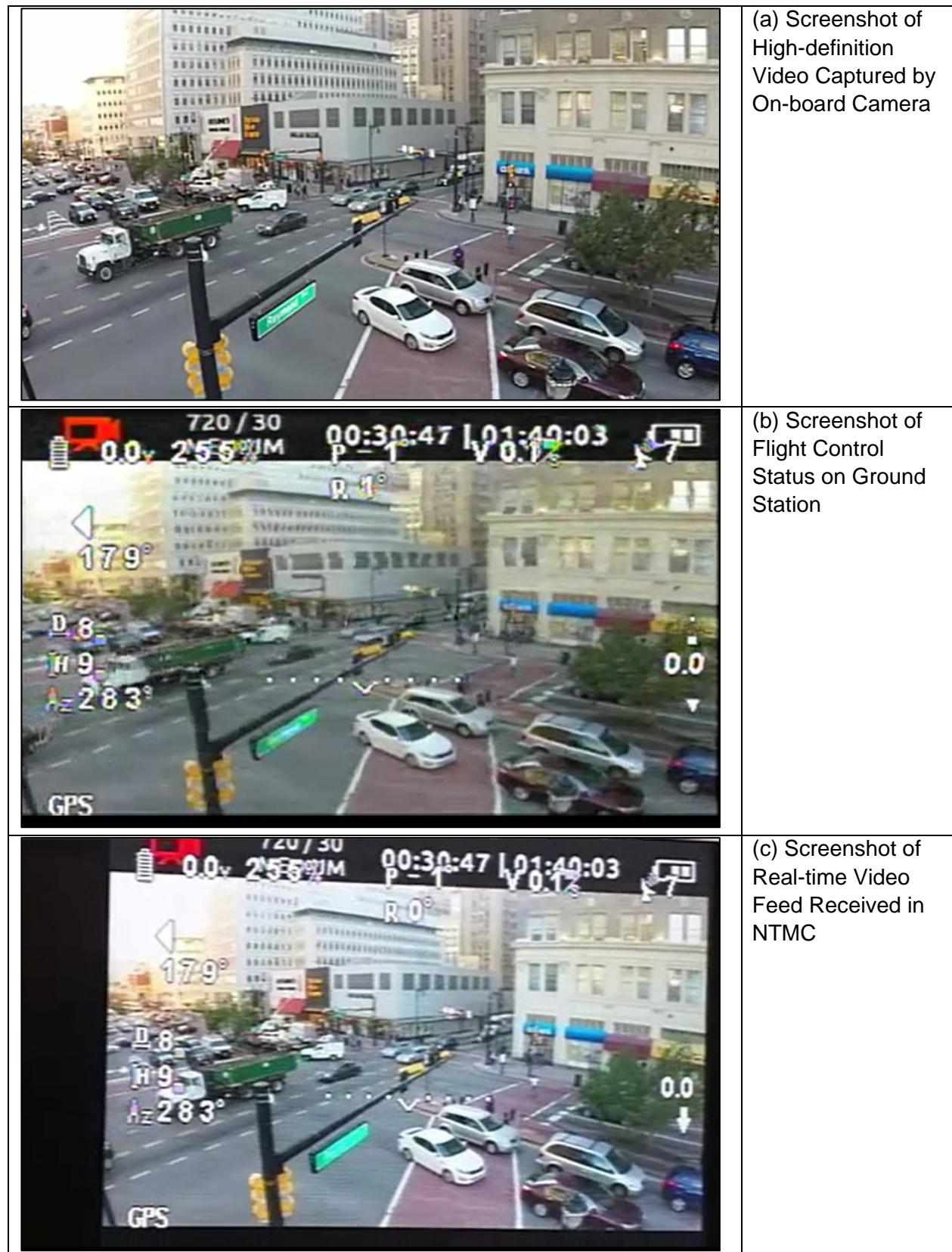
Figure 19. Video Quality Comparison

Despite the possible urban valley effect (e.g. surrounded by high-rise buildings) for GPS positioning, the UAV was able to maintain a stable position. Footage was captured by the on-board camera and then transmitted to the ground station and then eventually streamed to the TMC of Newark. **Figure 19** exhibits a side-by-side comparison of the video quality. Due to a sufficient 4G/LTE signal, the video conditions were of high quality for most of the time. No communication disruptions during streaming were observed during the test.

5.3. Photogrammetric 3D Reconstruction

The functional components of the LiDAR and photogrammetric 3D reconstruction are discussed in this section.

5.3.1. Air-TIMS Operation

The entire Air-TIMS system operates as it appears in **Figure 20**. When an accident happens, the Highway patrol will receive the accident report. Highway patrol will reach the accident site and they will prepare the UAV to be deployed. Highway patrol will control the UAV to fly over the accident site; in this situation, the UAV will be used as a live camera to broadcast the video of the accident site to the TMCs for further decisions and instructions. Meanwhile the UAV will take pictures and video from different angles to reconstruct a virtual 3D model of the accident site for further investigation. A reconstruction of the accident site enables the Highway patrols to clear the accident site faster.

In this following section, a detailed system design and functionality of Air-TIMS (Air Traffic Incident Management System) system has been provided.

ISI (Incident Site Investigation) as the major task of the Air-TIMS system will be executed after deploying the Air-TIMS at incident sites. Upon arrival at the incident site, the UAV will use its onboard high-resolution video cameras to take several overview video or pictures of the incident sites to identify the scope, involved vehicles, impact locations, tire marks location and other site information. An intelligent flight path planning algorithm will be developed to determine the optimal waypoint sequence and camera angles to take pictures of the incidents/accident sites for 3D accident reconstruction. Additional photos or video may be taken manually by on-site operators if needed. ISI is expected to be completed within 2-5 minutes. LiDAR scans will be utilized to calibrate the 3D model location.
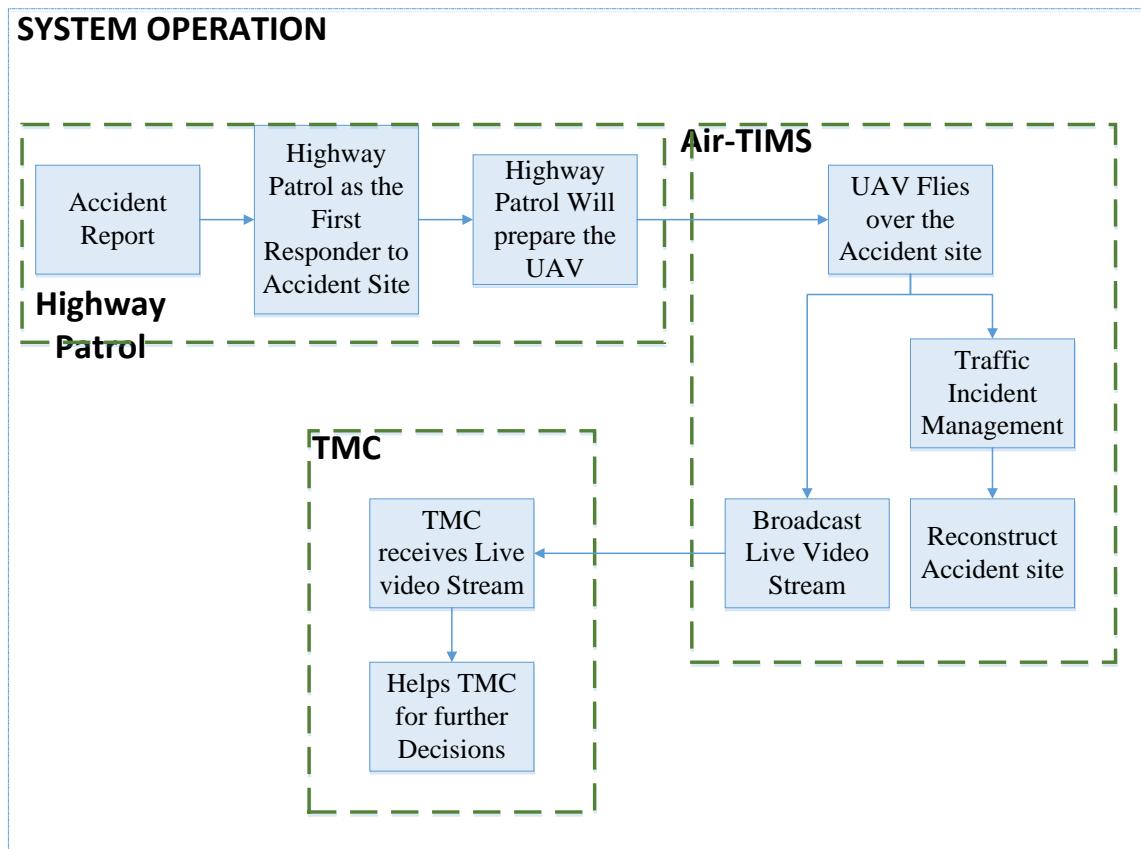
Figure 20. Air-TIMS Conceptual System Operation Flowchart

5.3.2. LiDAR Modeling Integration

Light detection and ranging (LiDAR) describes a method where a surface is sampled or scanned using laser technology. It analyzes a real-world or object environment to collect data on its shape and possibly its appearance (e.g. color). The collected data can then be used to construct digital, two-dimensional drawings or three-dimensional models useful for a wide variety of applications. The advantage of LiDAR scanning is the fact that it can record huge numbers of points with high accuracy in a relatively short period of time. LiDAR scanners are line-of-sight instruments, so to ensure complete coverage of a structure multiple scan positions are required. LiDAR has been widely used in many infrastructure applications such as infrastructure and construction site survey. Individual terrestrial laser scans can have millimeter accuracy. Registration of multiple laser scans typically can achieve centimeter accuracy. LiDAR data can be captured from static and mobile platforms. However, due to the weight and flight time limitation of UAVs, putting LiDAR equipment onto UAVs has drawbacks. At the meantime, the results from photogrammetric 3D reconstruction often has its own systematic errors such as the scaling and distortion in reconstruction process. In this study, we explored the potentials of using reference points collected through LiDAR scanning to enhance the 3D model reconstructed from photos.

5.3.3. System Components in LiDAR Scanning

Current laser scanner technology can be divided into 2 categories: static and mobile. Static LiDAR scanning is often referred to as tripod-based scanning in which a LiDAR scanner is placed on a tripod and the scanner rotates to generate spherical scanning patterns. The advantages of using this method are its high precision and its relatively high point density.

Mobile LiDAR (Laser Detection and Ranging), as shown in **Figure 21** is a growing remote sensing technology that has been used to collect geospatial data along highway systems for asset management applications. A mobile LiDAR system often consists of cameras and multi-return LiDAR sensors mounted on a vehicular platform whose positions and headings are precisely tracked by fusing data from the onboard GPS and an Inertia Measurement Unit (IMU). The LiDAR sensors typically incorporate lasers that operate at pulse rates up to 1 million Hz, producing dense and highly accurate point clouds along 200-400m-wide swaths; collected at forward speeds of approximately 10-50 MPH. In combination with the laser scanning, imagery is acquired by several digital cameras. The digital camera system is calibrated to the center of the scanner. The system can be mounted on a variety of platforms including road, rail, and marine vehicles.
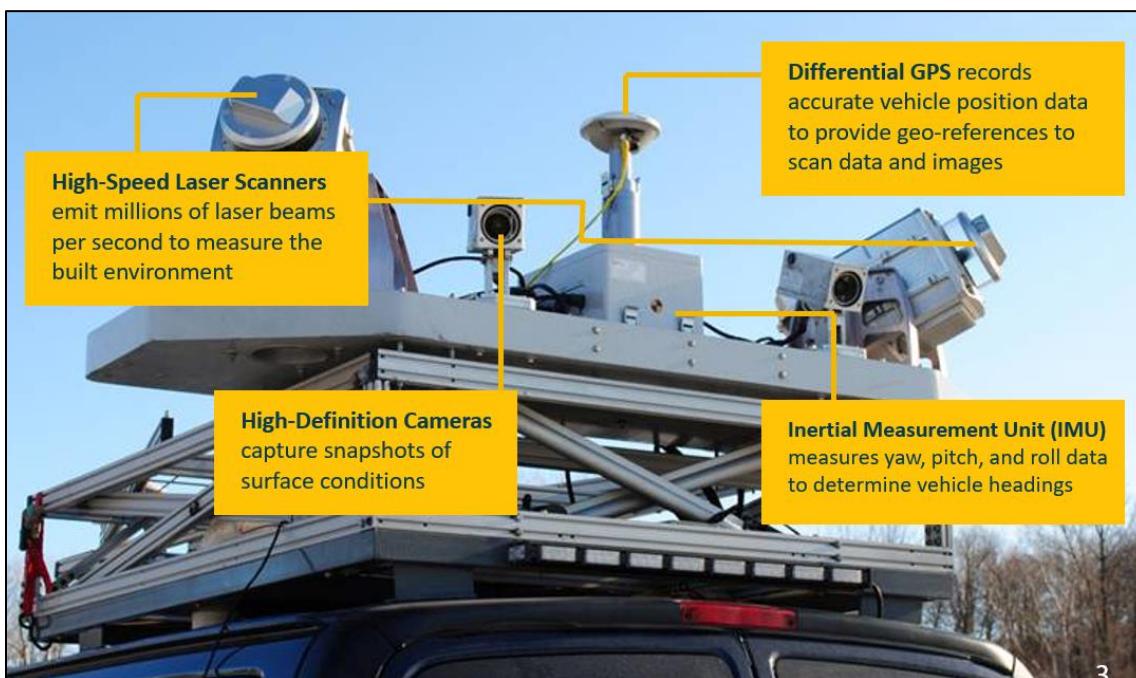

Figure 21. Mobile LiDAR Configuration

5.3.4. Procedures in Static and Mobile LiDAR Scanning

The key steps in static and mobile LiDAR scanning include scan planning, data acquisition, post-possessing, and data modeling.

Scan planning is the process of planning how the scans should be done. It typically involves planning scanning positions, scanning route, positioning of registration targets as seen in **Figure 22**, and placement of survey control points. This step may also involve gathering site information through maps such as Google Earth. The purpose of this activity is to optimize the number of scans and their coverage.
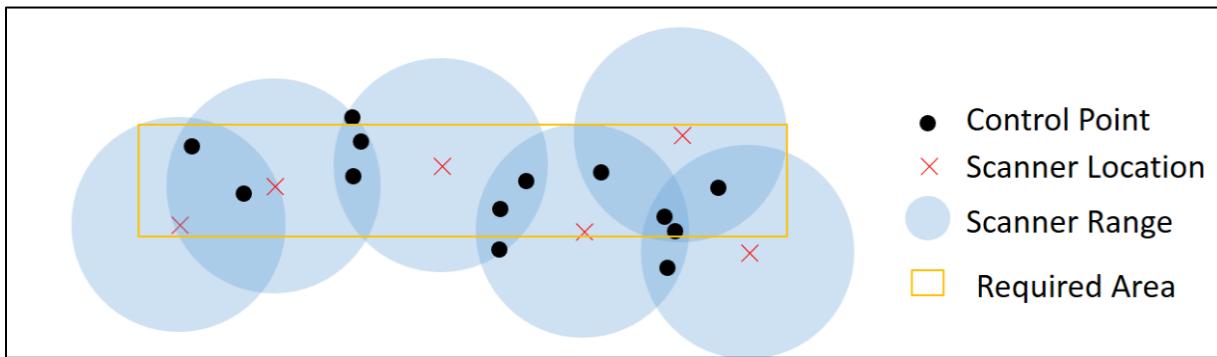

Figure 22. LiDAR Scanning Plan

Data acquisition is the actual onsite data collection process. A terrestrial scanner records the 3D information of the targeted objects and the built-in function in the scanner will automatically register all the points from a single scan to the local coordinate system of the scanner. Besides the point clouds data of each frame, mobile LiDAR scanning collects additional vehicle position information such as orientation and trajectory. Assuming the LiDAR scanner and all navigation units are rigidly connecting to the vehicle, the position information records the position of the local coordinate system (center of the IMU) of each frame referenced to a global coordinate system (GCS) (e.g. WGS 1984).

Geo-referencing is a process where point clouds from each scan (static) or data frame (mobile) are merged together based on intrinsic and extrinsic parameters. Terrestrial static LiDAR data are merged by applying a transformation matrix to the targeted point clouds. This transformation matrix is generated by identifying the 3D position transformation of identical features in the targeted scans to that in the referenced scan. In a static LiDAR scan, the identical features could be a target that remains in the fixed position or a common point or plane in both scans. Different from a static scan, mobile LiDAR data are geo-referenced by the position file captured in the system. This position file records the orientation and trajectory which helps to re-project all the points of each frame to the GCS.

Post-processing is a series of basic operations that convert LiDAR into readable deliverables to end users. These operations include, but are not limited to, data cleaning and filtering, classification, subsampling. Data filtering is an operation that removes the abundant information captured by LiDAR scanners, which thus reduces the amount of processed data. Classification is another key operation that assigns a category (such as "ground", "low vegetation") to the points

based on their geometry characteristics. These steps are particularly helpful in preparing LiDAR datasets for end-users for further feature extraction.

Data modeling is the processing of extracting useful features and information from the processed LIDAR data to support specific modeling activities such as producing as-built models. The detailed steps involved in this process varies significantly from application to application.

5.3.5. Air-TIMS Safety Detectable Risks

Detectable risks are associated with events that are apparent when they occur. If we consider the data link system used for communication between the ground control station and the SUAV as an example, a complete failure of this system will be readily apparent during operations. A clear indication of this, for example, would be a situation where the SUAV does not respond to commands from the ground station or where the data from the SUAV cannot be accessed by its operators. Such detectable failures can sometimes be dealt with by hardware/software redundancies or emergency procedures. In the most ideal case, these risks can be completely removed or dealt with once they are detected. In some instances, however, they cannot be completely removed and the best we can hope to do is mitigate their consequences.

5.3.5.1. Remote Control (RC) Lost Link

The RC transmitter outputs a Pulse Width Modulation(PWM) signal that is captured by the receiver and relayed to the autopilot. Each channel on the transmitter has a PWM range that is usually between 1100 – 1900 KHz with 1500 KHz being its neutral position. When radio calibration starts on the mission planner, all values will be at 1500 KHz. By moving sticks, knobs and switches it will set the PWM range for each channel. The autopilot monitors the throttle channel and if it notices a drop lower than THR_FS_VALUE (Default is 950KHz) it will go into failsafe mode. RC transmitters usually have a default range for each channel that goes from -100% to 100%, however most transmitters will allow to extend this to -150% and 150% respectively. In the default setup, bringing throttle to -100% will translate to a value close to 1100KHz and bringing it to -150% will translate to a value closer to 900 KHz. What we want to achieve is to let the receiver know that the throttle can go as low as -150% but still keep the autopilot control range between -100% and 100%. This means that when flying, throttle values will range between 1100 – 1900 KHz.

5.3.5.2. Mitigation Strategy

If we lose RC communication, the receiver, if it set up properly, will drop to the lowest known throttle value of ~900. This value falls below the THR_FS_VALUE and will trigger the autopilot to go into failsafe mode. First the autopilot will go into short failsafe (FS_SHORT_ACTN, 0=Disabled, 1=Enabled) when it detects loss of signal for more than 1.5 sec. The default setting for short failsafe is Circle mode.

▸ If the RC signal is regained during the short failsafe, the flight will return to auto mode.

▸ If the loss of signal is longer than 20 sec the autopilot will go into long failsafe (FS_LONG_ACTN, 0=Disabled, 1=Enabled). The default setting for long failsafe is RTL (Return to Launch).

▸ Once the long failsafe (RTL mode) has been entered at the conclusion of the short failsafe, the RTL mode will continue even if the RC signal is reacquired.

5.3.5.3. GPS Lost Link

In case of a GPS lost link, the pilot will put the drone in Alt mode which is the mode that only holds the drone at a same altitude. In this condition, the pilot will closely monitor and control the drone since in the Alt mode the drone can be easily drifted to any direction by wind. This process will continue until the GPS link is back online and then the pilot will switch the drone into GPS mode.

5.3.5.4. Air-TIMS Users and Stakeholders

During the process of Air-TIMS system, the transportation community will be affected and involved; this involvement will include users, operators and managers of road, devices and vehicles. The major users and stakeholders are:

▸ **Transportation Users**: People who are affected by the accident will get the benefit of efficient and faster accident site managements.

▸ **Highway Patrol**: The first responders to accident sites will deploy and operate the Air-TIMS.

▸ **Traffic Management Canters (TMC)**: TMC will receive the live video feeds of an accident to help the operators for further decision-making for accident management and alleviation, and for required emergency responds.

5.3.5.5. Air-TIMS Support and Maintenance

The Air-TIMS involves the following three factors for support and maintenance:
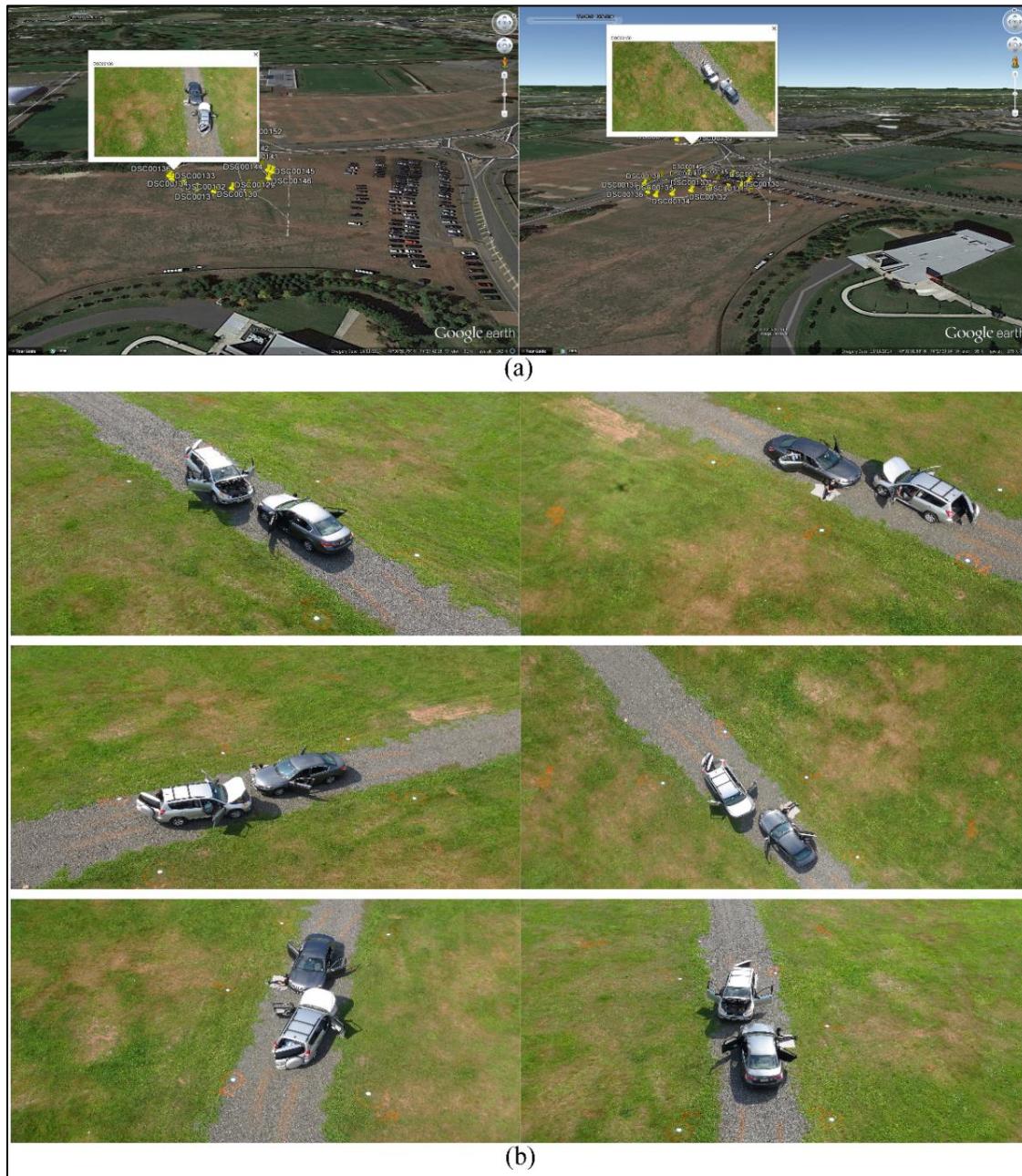
▸ **Mission Planning, Pilot Flying, and Image Shooting**: The flight plan will be created based on the accident site reconstruction needs. Therefore, defined number of points in a circle shape flight plan with defined diameter and altitude will be created. For better coverage of the accident site and 3D reconstruction, at least four more points on top of the accident will be assigned to the flight plan in higher altitudes than the base points. **Figure 23** illustrates: (a) the mission plan in the software; (b) a flight plan top view; and (c) a flight plan side view.

Figure 23. Flight mission plan: (a) in software, (b) Google Earth top view and (c) Google Earth side view

▶ **Assembly and Calibration**: The UAV was assembled by unfolding the UAV, attaching batteries to the arms, propellers, and camera mount installment. For an accurate flight, the UAV's campus was calibrated by connecting the UAV to Mission Planner software using the wireless transceiver on both the device and the UAV.

▶ **3D Model and Image-based Geo Referencing**: For Geo-tagging the pictures, the GPS coordinates of the pictures are required. Considering that the UAV takes control of the camera for shooting the pictures, the GPS location of the UAV at the time of shooting images is recorded on the flight log files. Based on the GPS coordinates of the flight plan

points and the accident site, the UAV stopped, turned towards the accident site, and took a photo at each of the defined points. The photos were transmitted to the ground station receiver shown in **Figure 24**. Images were saved on the laptop using a video image capture card for further processing. Once the UAV passed above, took the pictures, and transmitted the photos at each point, it landed automatically. The Mission Planner created all of the action steps, which were then uploaded to the UAV.


Figure 24. Images taken from the UAV: (a) superimposed on the Google Earth image of the location, and (b) various UAV camera angles

All the collected images are processed by Agisoft Photoscan Professional Version 1.1.6. Agisoft can generate independent depth maps out of images taken from multiple views of the accident site. Those depths maps are merged together by comparing common features in the overlapping areas of multiple pictures. Those common features are usually represented as vortex points and will be used to create dense point cloud and triangulated 3D meshes to create 3D models of the accident site.

Meanwhile, Agisoft also allows user to input the geo-coordinates of each image recorded by UAV flight log or camera GPS. This can help geo-register and scale the image-based reconstructed model. The rescaled 3D model will facilitate the measurement of tire marks, vehicle damage, infrastructure damages, etc. To find the GPS coordinates, the flight logs are downloaded from the UAV using the Mission Planner software. Agisoft also supports setting a coordinate system with ground control point (marker) coordinates. But in this study the reconstruction is based on image coordinates. The details of camera locations and the constructed 3D model are shown in **Figure 25**. The blue images in the figure depict the positions of the camera shooting locations and the directions of the pictures towards the accident site.
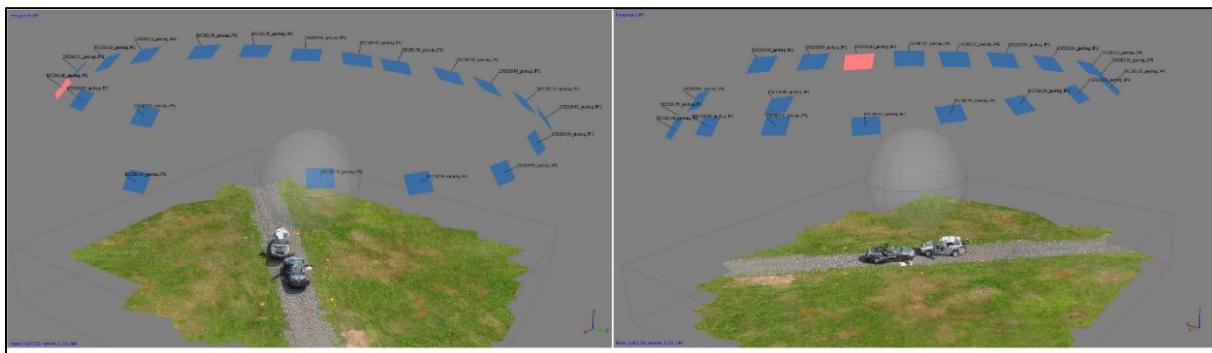
Figure 25. 3D reconstruction results from Agisoft: camera locations

5.3.6. The Orchestrated Accident Site

An orchestrated accident site was created to test the proposed methodology (test site is shown in **Figure 26**). The accuracy of the model was evaluated by conducting measurements on both the 3D model and the orchestrated accident site. The 3D model was constructed using the Agisoft software. The Agisoft creates a 3D model of the multiple pictures by creating a scaled 3D cloud of pixels from the original pictures. More pictures taken from different angles produce more accurate 3D models. **Figure 27** illustrates the angle of each picture taken from the drone towards the site. **Table 4** lists the coordinates of all the camera shooting positions.

Figure 26. Orchestrated accident site

Table 4. Image Coordinates

Image number	Longitude	Latitude	Altitude
DSC00128_geotag.JPG	-74.461222	40.516250	48.250000
DSC00129_geotag.JPG	-74.461222	40.516194	48.190000
DSC00130_geotag.JPG	-74.461278	40.516139	47.400000
DSC00131_geotag.JPG	-74.461306	40.516111	47.900000
DSC00132_geotag.JPG	-74.461389	40.516083	48.250000
DSC00133_geotag.JPG	-74.461472	40.516083	48.360000
DSC00134_geotag.JPG	-74.461528	40.516083	46.870000
DSC00135_geotag.JPG	-74.461611	40.516111	45.870000
DSC00136_geotag.JPG	-74.461639	40.516167	46.000000
DSC00137_geotag.JPG	-74.461694	40.516194	46.310000
DSC00138_geotag.JPG	-74.461694	40.516250	46.720000
DSC00139_geotag.JPG	-74.461694	40.516306	47.160000
DSC00140_geotag.JPG	-74.461639	40.516361	47.450000
DSC00141_geotag.JPG	-74.461611	40.516417	46.560000
DSC00142_geotag.JPG	-74.461528	40.516417	46.860000

Image number	Longitude	Latitude	Altitude
DSC00143_geotag.JPG	-74.461444	40.516444	45.310000
DSC00144_geotag.JPG	-74.461389	40.516417	44.570000
DSC00145_geotag.JPG	-74.461306	40.516417	46.610000
DSC00146_geotag.JPG	-74.461278	40.516361	46.500000
DSC00148_geotag.JPG	-74.461222	40.516250	44.270000
DSC00149_geotag.JPG	-74.461361	40.516278	63.880000
DSC00150_geotag.JPG	-74.461472	40.516194	63.740000
DSC00151_geotag.JPG	-74.461556	40.516250	63.580000
DSC00152_geotag.JPG	-74.461417	40.516333	63.820000

Figure 27. 3D reconstruction results from Agisoft: camera locations

5.3.6.1.   Results

Figure 27 shows the dense cloud of the 3D model. It can be observed that the general shape and key features of the accident site such as roof outline, open doors, open hood, tail lights, tires, car body, and the orchestrated injured personnel outside of the vehicle have been captured. However, due to the glare that leaves different colors on the smooth surface of the car such as windows and roof panels, these facets are not fully captured, causing missing points at the corresponding

locations. To compensate, the missing points require more pictures from different angles which can be taken to provide more overlaps between the images. Another way of reducing the glares in the photos is to use the polarized filter on the camera lens. Those options are slated to be tested in future flights.

5.3.6.2.   Measurement Result Analysis

A measurement comparison was implemented to investigate the accuracy of the proposed methodology. Two vehicles were used in this study, a Toyota RAV 4 and a Honda Accord. Measurements were conducted on both of these vehicles. The measurement comparisons have been summarized in Table 5.

Results show the high accuracy of the 3D model. Seventy-five (75) percent (9 out of 12) of measurements were within 5 percent error range. However, the three measurements show significant errors, such as the bumper to bumper length in Honda Accord. These errors derived from the missed matched pixels detected by the software due to illumination of the sun on the same surface of the vehicles taken from different angles. Sunlight reflection in a few pictures created a glare that resulted in a missed detection of matched pixels in the software.

Table 5. Measurement Results

| Length(cm) | Toyota RAV 4 2010 | | | | Honda Accord 2011 | | | |
| | Actual | Model | Error | | Actual | Model | Error | |
			Rel.	Abs.			Rel.	Abs.
Tire Diameter	70	69.2	1.20%	0.9	64	65.5	2.40%	1.5
Tire Center to Tire Center	268	273.2	1.93%	5.2	280	283.8	1.36%	3.8
Bumper to Bumper	447	461.3	3.19%	14.3	411	494.8	20.38%	83.8
Height	165	163.8	0.75%	1.2	142	138.4	2.54%	3.6
Taillight to Taillight	130	125.6	3.37%	4.4	155	159.2	2.72%	4.2
Roof Width	190	208.9	9.94%	18.9	125	140.1	12.11%	15.1

5.3.6.3.   LiDAR Reference Model Reconstruction Results

To provide baseline data for validating the accuracy of the 3D data generated from UAV-based imagery data, static scanning was performed to capture high-fidelity 3D data. Static scanning was performed prior to and after the occurrences of simulated car accidents. A total of 12 scans were performed, with each lasting around 10 minutes, to capture the accident scene. The image in the top left corner in Figure 28 shows the colorized point cloud of the scene pre-accident, and the remianing images in show the colorized point clouds of the post-accident scenes from different

viewing angles. These point cloud data provide very accurate baseline data for the performance evaluation of drone-based accident reconstruction methods.

The generated 3D model experienced issues reconstructing a smooth surface of cars, due to the different illumination caused by reflection and glare captured by video cameras on a sunny day. Sunlight reflection can cause different colorizations for the same feature locations on cars not being correctly matched by photogrammetric reconstruction. To reduce the reflectance of the sun on the surfaces, polarized filtering lenses may be potentially used in future test flights. The experiment also generates a 10-minute, 1080p-HD, 60-frame/second video that can be used to generate thousands of snapshots and to produce significantly more images for 3D reconstruction. The difficulty lies in Geo-tagging those images based on the 5Hz GPS readings from the UAV flight logs. Another alternative is to conduct LiDAR pre-scans of the corridor to be deployed by Air-TIMS and then use feature locations such as lane markings, mileposts, and traffic signs as reference points for faster onsite 3D reconstruction. The key is to use the references points to reposition and rescale the photometric reconstruction results without the need for onsite control point survey and photo Geo-tagging.

Figure 28. LiDAR Reference Model Reconstruction

6. Conclusions and Recommendations

Improvement in UAV technologies such as autonomous flight mode and GPS-based position holding make the technology more suitable for applications in traffic operations, especially for rotary-wing UAVs with the VTOL capabilities. Furthermore, mass production and civilian usage of UAVs have brought down the unit price significantly, making it more and more affordable and cost-effective for use in transportation applications. The flexibility which SUAVs provide is a perfect complement to the traditional stationary sensor networks, as demonstrated on the field deployment tests. Live video streaming into the TMC showed promising results for using SUAVs for traffic incident monitoring. Via a commercial 4G/LTE network, the TMC was able to receive live footage of the incident scene and display it on- screen as the incident clearance was in progress; this is a feature which will help the operators in TMC to prioritize limited resources as necessary.

Deploying SUAVs could also assist law enforcement with documenting the accident scenes and with expediting incident clearances. To this end, in addition to the incident monitoring and management application, the research team conducted field tests for the traffic incident scene reconstruction application by utilizing a mid-size rotary-wing UAV system. Namely Air-TIMS, the system is equipped with a high-resolution camera, stabilizing camera gimbal, HD video transmitter, and ground control station. Combined with software such as Mission Planner, Geo-tagging script, and Agisoft Photoscan, the proposed system can be used to reconstruct 3D models of accident sites. An orchestrated accident site is configured to evaluate the proposed system. Twenty-five (25) pictures had been taken from different angles by UAV cameras planned through a waypoint plan. Once the pictures were taken and transmitted to the ground station, the pictures were Geo-tagged using Agisoft. The Geo-tagged pictures were used in the Agisoft software to create a correctly scaled 3D model of the accident site. To compensate for the shift of the model in the real world due to GPS errors in the UAV, reference points were surveyed to find the correct relative location of the model with respect to earth coordinates. The measurements in the 3D model compared to the real world measurements at the site shows promising accuracy, thus illustrating the feasibility of the approach.

To operate an UAV, the FAA requires every user to apply for a COA. The complete process of obtaining the FAA COA, based on guidelines at the time this document was assembled, has been described and presented in detail. The process starts with an N-number registration. Afterwards, the pilot and co-pilot should obtain the required certifications by passing the private pilot knowledge test and obtaining medical certification. In the next step, the UAV should be insured. The next steps involve adding the UAV to a blanket COA. Afterward, the airworthiness certification should be obtained from the FAA. In the final step, the ISRB will review the documents to evaluate the applicant. Approved applicants will obtain the designated COA.

With the promising applications of SUAVs, the recommendations are summarized as follows:

1. The current UAS system may be able to be retrofitted onto NJDOT's Safety Service Patrol Vehicles. The NJDOT staffs may deploy the SUAVs for a real-world traffic incident monitoring scenario, should an accident happen.

2. The UAS may be able to be integrated into the NJDOT TMC that is equipped with an automatic live streaming program, and the video link between the ground station and the TMC could be established by a simple one-click of a button by the pilot operator upon arrival at the scene.

3. The video-encoding method could be changed to stream high-definition footage under a higher compression rate.

4. The applicability of similar UASs could be explored to fully study the most cost-effective UASs that can be tailored to different applications.

5. Video analytics technology could be integrated with the UAS to extract traffic information (e.g. volume, queue length) programmatically.

6. Due to the visual coverage of the MUAV, the application of environmental surveying, large-scale roadway construction sites monitoring, etc., are also worthy of exploration.

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