

A mini-UAV VTOL Platform for Surveying Applications

Kuldeep S. Rawat*, Ellis E. Lawrence

* Department of Technology/Aviation, Elizabeth City State University, North Carolina, USA

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ABSTRACT

In this paper we discuss implementation of a mini-Unmanned Aerial Vehicle (UAV) vertical take-off and landing (VTOL) platform for surveying activities related to highway construction. Recent advances in sensor and communication technologies have allowed scaling sizes of unmanned aerial platforms, and explore them for tasks that are economical and safe over populated or inhabited areas. In highway construction the capability of mini-UAVs to survey in hostile and/or hardly accessible areas can greatly reduce human risks. The project focused on developing a cost effective, remotely piloted, fuel powered mini-UAV VTOL (helicopter) platform with certain payload capacity and configuration and demonstrated its use in surveying and monitoring activities required for highway planning and construction. With an on-board flight recorder global positioning system (GPS) device, storage, telemetry, inertial navigation sensors, and a video camera the mini-UAV can record flying coordinates and relay live video images to a remote ground receiver and surveyor. After all necessary integration and flight tests were done the mini-UAV helicopter was tested to operate and relay video from the areas where construction was underway. The mini-UAV can provide a platform for a range of sensors and instruments that directly support the operational requirements of transportation sector.

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Corresponding Author:

Kuldeep S. Rawat,

Department of Technology/Aviation,

Elizabeth City State University,

1704 Weeksville Rd, Elizabeth City, North Carolina 27909, USA.

Email: ksrawat@ecu.edu

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) represent one of the most important technologies in the field of aeronautics due to their range of applications, mission flexibility, and high performance at low operating costs. UAVs are aircraft without crew and passengers that could either be remotely piloted by ground or autonomously carry out an application. Their effectiveness is due to the possibility to reach hostile and inaccessible areas without exposing humans to hazards and dangerous situations. Moreover, the internal space can be fully designed in order to place payload (sensors and /or cameras) and the on-board systems.

Due to the high cost and high risk to operate traditional aircraft missions under hazardous flying conditions, researchers are beginning to turn to unmanned aerial vehicles (UAVs) as a low-cost, low-risk alternative. UAVs have been a topic of extensive research for military applications since 1950s. UAVs were used as prototypes in World War I and II for intelligence gathering. In the last decade, Defense Advanced Research Projects Agency (DARPA) initiated several projects to increase use of UAVs in military applications [1].

The interest in mini-UAV for civilian applications has rapidly grown in last few years due to emergence of sophisticated hardware and software systems/algorithms to support semi-autonomous or fully-autonomous control [2] [3]. In addition, the availability of low cost miniaturized global positioning system

(GPS) device, inertial sensors, computational hardware, power plant, airframe materials and other integrated systems has made small UAVs affordable for civilian applications [4].

UAVs can be equipped with a variety of imaging devices including day and night real-time video cameras to capture real-time video; sensors such as digital video, thermal and infrared cameras, hyper-spectral sensors, radar, and chemical and biological sensors. With real-time data transfer capabilities to the ground station, UAVs can record necessary information, such as weather, fire and flood information, and relay data to the ground station.

UAV design and manufacturing companies are now working with commercial customers to develop mini and/or small UAVs and associated technologies that are well suited for myriad of civilian applications. These areas include oil and gas survey and monitoring requirements, forestry management, law enforcement, agriculture, traffic monitoring, and insurance underwriting and asset management [5]-[8]. All these application share the common requirement for surveillance capabilities over large areas and/or long timeframes.

Civilian UAVs have already demonstrated potential in a wide variety of applications. In 2005 researchers at the National Oceanographic & Atmospheric Administration (NOAA) flew a 6-ft.-long UAV, known as Aerosonde into the heart of tropical storm Ophelia [6]. Such flights are currently conducted by piloted transport planes at a relatively safe altitude of 10,000 ft. But because a UAV puts no crew at risk, the Aerosonde can be flown a few hundred feet above water, where winds whip at 175 mph and waves can top 60 ft.

UAVs have proven to be ideal for acquiring imagery over dangerous environments such as forest fires, where long endurance missions can monitor situation without risking human flight crews. The U.S. forest service in collaboration with NASA flew a modified Predator B, known as the Altair, over a 40,200-acre fire near Palm Springs, California [8]. The Predator B UAV flew for 16 hours relaying down images that allowed the fire management team to pinpoint the perimeter of a dangerous blaze that killed five firefighters.

The law enforcement community has been in forefront of using UAVs in civilian air space, and has successfully reaped its enormous benefits [9]. For law enforcement applications UAVs have proven to be more economical to operate and can cover more territory than manned aircraft. The Sacramento Police Department demonstrated their UAV, designed and built in-house to enhance the department's existing airborne technology program [10]. The UAV with video down link communications has given the department an affordable and a quieter alternative to the manned hovering helicopter during incidents.

Extensive research has been conducted in the past few years on deploying mini and/or small unmanned platforms for civilian applications [11]. Researchers have tried experimenting on fixed wing aircraft, helicopter, observation balloons, and satellites. These research projects have proven that UAVs may be employed for a wide range of applications, particularly related transportation operations and planning.

Over the past few years, the mission of roadway transportation agencies has evolved from solely providing roadway infrastructure to focusing on the needs of the traveling public, management and operations, and improved performance of the surface transportation system. This requires collection of precise and accurate information about the state of the traffic and road conditions. Aerial view provides better perspective with the ability to cover a large area and focus resources on the current problems [11]. The Virginia Department of Transportation (VDOT) in collaboration with the National Consortium on Remote Sensing in Transportation (NCRST) to demonstrate the feasibility of an unmanned Airborne Data Acquisition System (ADAS) for real-time traffic surveillance, monitoring traffic incidents and signals, and environmental condition assessment of roadside areas [12].

Widespread deployment of UAVs for transportation applications will require a number of specific issues such as safety, liability, and privacy to be addressed. These issues prompted the U.S. Department of Transportation's Volpe Center to sponsor a conference to develop a roadmap for deploying UAVs in Transportation [13]. The document depicting the roadmap acknowledged that there is a great deal of interest in expanding and demonstrating the use of UAVs. However, the roadmap document, also noted a number of barriers, most of which are institutional. The effort forged a plan to address these barriers to deploying UAVs for transportation applications.

The remaining section highlights UAV research work in the area of transportation conducted at universities such as University of Florida, Georgia-Tech, Ohio State University, and University of Washington.

The University of Florida (UFL) initiated Airborne Traffic Surveillance System (ATSS) project focused on a proof-of-concept UAV project for monitoring remote and rural areas of the state of Florida [14]. The ATSS proof-of-concept project also evaluated the feasibility of the wireless communication systems, as well as switching of the video.

Georgia Tech Research Institute's (GTRI) conducted the Traffic Surveillance Drone project funded by the Georgia Department of Transportation and the Federal Highway Administration's Priority Technology

Program [15]. The project focused on the development of a generic low-cost vertical take-off and landing (VTOL) UAV testbed that may be used to flight test other research projects such as advanced controllers, fault-tolerance algorithms and autonomous operation algorithms.

The Ohio State University (OSU) in collaboration with the Ohio Department of Transportation (ODOT) performed field experiments on the use of UAVs to collect data about freeway conditions, intersection movement, network paths, and parking lot monitoring. They were using the collected information for space planning and distribution as well as providing quasi real-time information to travelers [16].

The University of Washington (UW) in collaboration with the Washington State Department of Transportation (WSDOT) and the Georgia Tech UAV Research Facility conducted several experiments including the evaluation of UAV use on mountain slopes above state highways to control avalanches or capturing aerial images for data collection and traffic surveillance purposes [17]. The project showed considerable potential for aerial roadway surveillance and avalanche control using UAVs.

In transportation application such as highway construction, the agencies have to survey swamps, land, rivers, streams, mountainous terrains or areas that are not safe for humans to physically survey or monitor. Some private companies have been flying manned aircrafts for commercial usage and survey. However, this approach is costly. Also, the manned aircraft cannot be flown in bad weather, or regions which are potentially unsafe for the operators. A small UAV with necessary sensors and control circuitry is a cost-effective and safe alternative to manned aircrafts. In the following section, a remotely piloted mini-UAV helicopter platform specifically developed for surveying applications in highway planning and construction is discussed.

2. RESEARCH METHOD

Whenever highways, roads, dams, retaining walls, bridges or residential structures are to be built, surveyors are required. Surveyors spend a considerable amount of time and effort to make adequate investigation to determine if there are encroachments, gaps, lap pages, or other irregularities along each line surveyed. In highway construction, a successful project requires civil engineers and surveyors to accurately measure distances. The traditional measurement method required transits equipped with lasers and computer-related technology and chains (tape measure) to measure from point to point that requires a clear line of sight. To obtain this line of sight, trees had to be cut and destroyed which consumed countless of man hours and accuracy was often questioned. A low cost mini-UAV equipped with an advanced flight recorder global positioning system (GPS) can fly above obstacles such as trees, mountains, or water and located points with better accuracy. Often times on a deed, one is provided with such information as so many degrees and minutes in a certain direction. Given this information and the GPS coordinates, one can fly these coordinates with accuracy once the starting point is located.

The preliminary research into small Unmanned Aerial Vehicles (UAVs) at ECSU began as a grant project funded by the North Carolina Department of Transportation (NCDOT) / Federal Highway Administration (FHWA) [18]. The goal of this project was to apply UAV technology for surveying applications related to highway planning and construction. The initial focus of the research was to look into UAV as a tool to aid NCDOT/FHWA in specific areas of their work. After looking into some of the projects that NCDOT/FHWA were focused on, it was decided that one central idea should be focused on for the UAV application; in this case land surveying was chosen as the focus point for the research project. UAV-based aerial surveys offer a viable and cost effective alternative for mapping areas too small for traditional manned aircraft. The ability to gather and process data rapidly in a variety of weather conditions makes UAV particularly useful for applications involving cut-and-fill analysis and volumetric survey.

The project team started with studying various UAV platforms that would have the ability to survey land in an efficient manner. This means that the unit would need to be easy to transport and require as little maintenance as possible for day to day use. The UAV would also need to be able to carry the necessary payload for the task and be capable of taking all of its measurements and data recordings while requiring as few operators as possible in order to lower deployment costs. The team looked into high end Radio Controlled (RC) flight vehicles that could be easily adapted for UAV platform. Investigation into RC flight vehicles led to three possible options: Radio Controlled Planes (Fixed-wing), Radio Controlled Blimps (Lighter than aircrafts), and Radio Controlled Helicopters (Rotary-wing). Advantages and limitations of each of these UAV platforms are presented in Table 1.

Table 1. Comparison between different UAV platforms

| UAV Type | Advantages | Limitations |
|---------------------------|---|--|
| Planes (fixed-wing) | Higher Speed Greater Range Easier to control | Too fast for still imagery and many measurement systems unable to hover |
| Helicopters (rotary-wing) | Vertical Takeoff and Landing (VTOL) Capability Hovering Capability for measurements Decent Payload capability | Difficulty of control Shorter range |
| Blimps (lighter than air) | Flight time greatly extended Stationary floating ability (offers the same advantage as helicopter hover) A lot less components to replace and harder to crash | High cost Less payload by size |

A careful examination of our application and advantages/disadvantages for each unit discussed above led to selection of UAV helicopter as a suitable platform since payload was so critical and the hovering ability was also desired for some of the aerial imagery that was planned for the project. Once the basic UAV platform was selected, other parameters such as takeoff weight, Rotor blade length, endurance speed, endurance time, weight of fuel, weight of avionics, engine power and weight, airframe weight, and cost were taken into consideration in building a fully operational mini-UAV helicopter platform.

It was decided early on that the mini-UAV platform must be very rugged – a machine that is solid, dependable and reliable. The mini-UAV platform was custom built using a .90-sized model designed for 810 mm main rotor blades (or longer) and powered by the Zenoah G260PUH gas engine with built-in air box and exhaust as shown in Figure 1. This engine was used because it runs smoothly, powerfully, reliably and importantly did not produce any noticeable radio frequency interference. It uses mechanical mixing, where each cyclic and the collective servos perform a single task with push/pull controls. A stacked side-frame structure and single stage gear reduction is used with the tail driven by a crown gear and pinion with a tube drive. The longer main blades were used to increase the payload lift capacity of the mini-UAV platform.

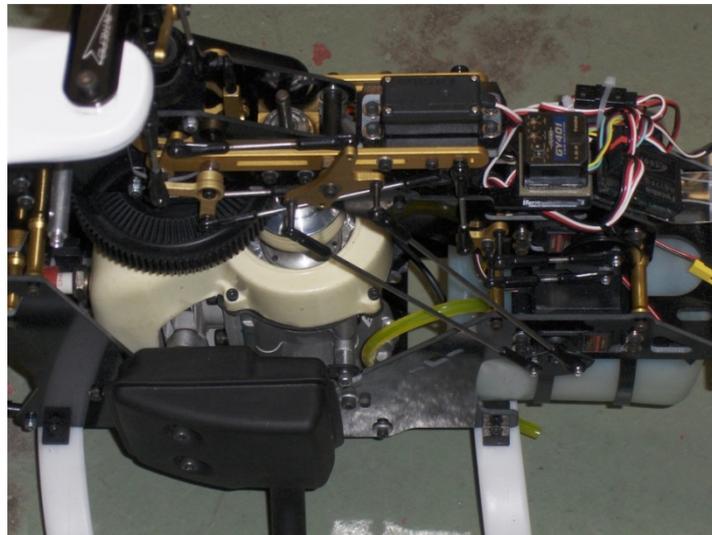


Figure 1. Power plant used on mini-UAV helicopter

The team preferred gas engine even though it is heavier and does not produce as much power per cubic-centimeter as glow engine. The advantage is in the fuel economy, both in gasoline being considerably cheaper than glow fuel and the fuel consumption is about half (or less) than an equal power glow engine. Another feature is the reliability, as gas engines are lightly stressed and so last a very long time, they are easy to use – electronic (CDI) spark plug ignition, requires just pulling the recoil starter, the carburetor includes a diaphragm pump with a priming bulb making for very easy operation. A simple comparison with current high performance .90 glow engines showed the G260PUH produces less power 2.4 PS (2.37 hp) at 12,000 rpm

versus 3.3 PS at 15,000 rpm, but a similar amount of torque of 220 oz/in torque at 9,000 rpm versus some 240 oz/in at 13,000 rpm.

An assembled open tail gearbox was used to provide wide support for the output shaft. The machined blade grips are supported on dual races and a thrust race, the pitch slider is also ball raced and the pitch links are fully articulated. As shown in Figure 1, a Zimmermann muffler was used as a part of exhaust system to reduce exhaust noise. The large fuel tank was assembled and held in place with a pair of cable ties.

In view of the weight of the mini-UAV (about 5.5 kg/12 lb 2 oz) without blades or fuel, an Arizona Regulator which uses a Fromeco Peerless 2400 mAh 2-cell Lithium-ion supply was used. The Regulator supplies a dual output, a fixed 5.0 V for the gyro and the second feed to the receiver can be adjusted from 4.95 – 6.25 V. It has an output of 17 Watts (28 Watt with forced air flow), which is some 3 amperes continuous and bursts of 4.5 amperes. This gives a 6 V set up to power the Futaba S9204 and S9206 servos and so make the most of their power.

Once the mini-UAV helicopter was installed with the reliable Zenoah G26 engine, and 800 mm carbon fiber blades, the RF camera system was mounted on the front. Putting the camera equipment on the front keeps from having to utilize a tall landing gear and the inherent problems associated with it. A front mounted camera also allows a clear 270-degree field of view and keeps the mini-UAV helicopter balanced.

The payload capacity enabled the mini-UAV helicopter to carry a video camera for the purpose of remote surveillance/monitoring, a transmitter to relay the video data, an advanced flight recorder with antenna and built-in GPS, and a battery pack as shown in Figure 2.

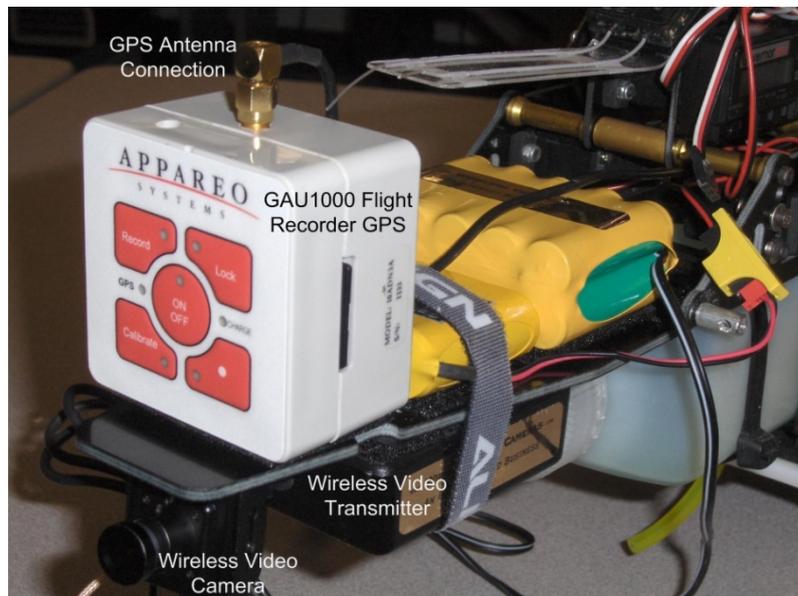


Figure 2. Mini-UAV payload (flight recorder, wireless video camera/transmitter, battery pack)

The mini-UAV helicopter was built with following technical specifications:

Weight: 12 pounds 2oz without fuel or main blades

- Overall Length: 58 inches, 90-sized model
- Power plant: Zenoah G260PUH90 gasoline engine capable of 2.37 hp @ 12000 rpm, and a torque of 220 oz-in at 9000 rpm
- Futaba GV-1 rotor speed governor, GY401 heading hold gyro, S9254 and S9202 servos
- Main Rotor: Custom made 810 mm carbon fiber blades
- Dual Hydrimax 6V NiMH battery packs 2000 mAh each
- Maximum payload of about 15 pounds

The mini-UAV helicopter was programmed to operate with a Futaba 9CHP 9-channel radio connected electronically using the Heli-Chair flight console setup. The complete mini-UAV helicopter platform (without canopy) depicting internal components and payload is shown in Figure 3.

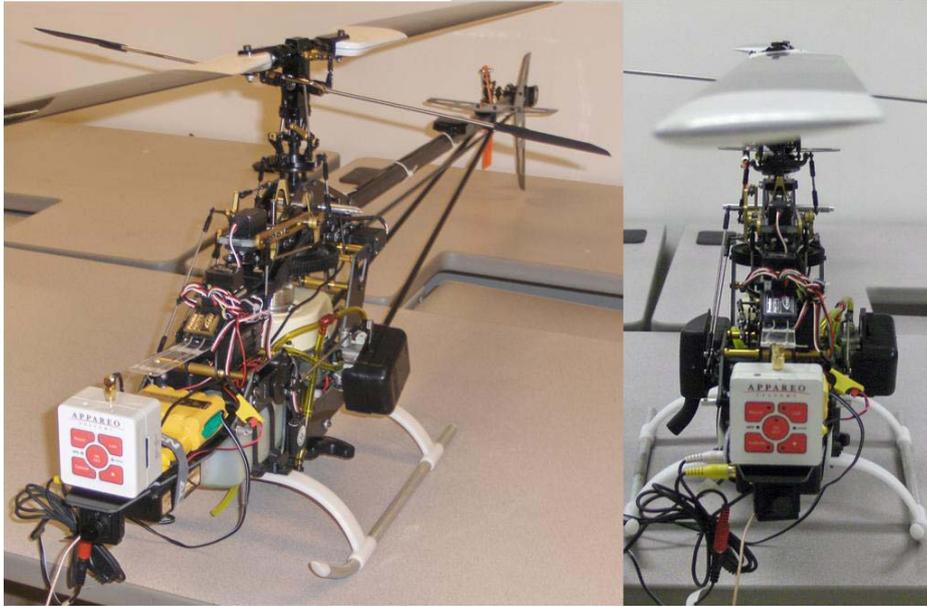


Figure 3. Mini-UAV helicopter platform

3. RESULTS AND DISCUSSION

The mini-UAV was powered by two 6V battery packs, 2000mAh each, that are in parallel. One hour is the maximum endurance of the electrical system. For this mini-UAV helicopter configured with a heading hold gyro and governor (GV-1), the electrical system draws approximately 3 amperes during flight.

The ground station is shown in Figure 4. The ground station consisted of a low power, light weight, 5.8 GHz frequency receiver with a range of up to 1 mile and a virtual reality headset. The headset enables first person view (FPV) for remotely piloted flight. By wearing virtual reality (VR) goggles, the surveyor or the remote 'pilot' can see what the camera mounted on the mini-UAV sees. This FPV flying experience not only facilitates observing the land terrain, but also helps in controlling the mini-UAV remotely during flight.

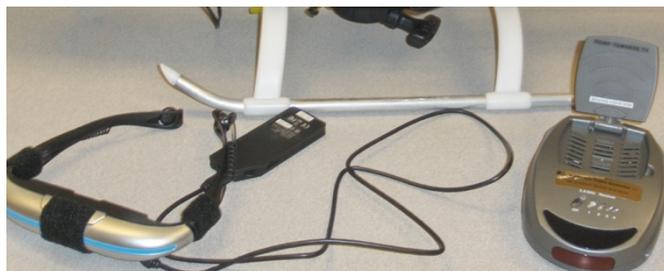


Figure 4. Ground station receiver and headset

Professional RC pilots were invited for piloting and training personnel to pilot the UAV helicopter. The test pilots assisted the UAV team in gathering area surveying data and imagery for this project. Figure 5, shows the mini-UAV helicopter in flight at a construction site.



Figure 5. Mini-UAV helicopter during test flight around construction site

During test flights, the mini-UAV was able to hover about 30 minutes to complete fuel exhaustion. It was capable of lifting 15lbs dead load, and could instead carry 10 pounds payload, 5 pounds extra fuel in a heavily loaded condition, extending flight times to beyond 1 hour. Because the helicopter weighs 13lbs, when carrying 15 lbs extra, the fuel consumption could double because the power required would double. This is in a hover, if the UAV is in forward flight, the amount of power required decreases a great deal due to translational lift.

The GAU 1000 flight recorder GPS mounted on the mini-UAV helicopter records altitude, air and ground speed, pitch, roll, yaw, latitude and longitude coordinates, flight times, and trip distances. Once the mini-UAV helicopter was operated over the land area used during flight testing, the recorded data was transferred to a lab computer loaded with Flight Evaluator software. The Flight Evaluator software allowed for satellite imagery lay over showing the terrain the unit flew over and can also be used for area calculations by using the longitude and latitude coordinates. The screen shot from the Flight Evaluator software is shown in Figure 6.



Figure 6. Flight evaluator software depicting satellite image lay over

Some of the implementation challenges the project team had to tackle during the project were in the area of aerodynamics, propulsion, flight control and sensing, telemetry, and transmitted data quality. All these challenges were further influenced by the ground-based systems needed to operate the UAV. But after all necessary integration and flight tests were done the mini-UAV evolved into ever more capable platform that will be economical to operate and will fly safely over populated and inhabited areas.

Furthermore, the mini-UAV helicopter could also be used to take high-resolution pictures of highways to inventory their features and conditions at a very low cost and in short time. These pictures could be sent to improve the geographic information systems (GIS) databases with photos of ongoing and recent highway construction, structures, and maintenance issues.

The final mini-UAV helicopter platform tests demonstrated:

- Flight Duration: 30 minutes (fuel limitation), 1-hour (battery life)
- Capable of first person monitoring/recording and GPS data recording
- Flight Team: Two members; the pilot and second person to monitor flight information

4. CONCLUSION

The implementation of a mini-Unmanned Aerial Vehicle (UAV) vertical takeoff and landing (VTOL) platform for surveying activities related to highway planning and construction is seen as a worthwhile endeavor when we consider the sophisticated sensors, computing hardware and software, and communication technology available today. In this paper, development of mini UAV helicopter platform that can be used for surveying areas for highway construction or other transportation related projects was discussed. The mini-UAVs offer a solution to surveying problem because they can operate safely at altitudes below full-size air traffic and their size, speed, and weight poses a much smaller threat to the public. Traditional method of land surveying for highway construction are time consuming, requires cutting of trees for clear line of sight, and has questionable accuracy. In addition, performing surveys in hostile and/or hardly accessible areas can increase human risks. A low cost mini-UAV with on-board image and video capturing capability and a flight recorder GPS can greatly improve the surveying procedure for highway construction. The project involved studying various UAV platforms and custom building a low cost mini-UAV with an on-board flight data recorder and video capturing capability. The mini-UAV can be applied for not only surveying applications required for highway construction but also for other transportation applications where manned aircrafts are expensive and infeasible to operate.

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BIOGRAPHIES OF AUTHORS



Kuldeep S. Rawat is the Chair of the Department of Technology and Director of Aviation Science Program at Elizabeth City State University (ECSU). He holds a PhD in Computer Engineering from the Center for Advanced Computer Studies at the University of Louisiana – Lafayette. He is also the Director of Unmanned Vehicle Systems Lab at ECSU and co-directs the National Summer Transportation Institute at ECSU.



Ellis E. Lawrence is Professor of Technology in the Department of Technology at Elizabeth City State University. He holds an EdD in Vocational and Technical Education w/cognate in Industrial Engineering from Virginia Polytechnic Institute. He also serves as the Director of National Summer Transportation Institute at ECSU, funded through the Federal Highway Administration (FHWA).