The goal of this project is to enhance the situational awareness capabilities of law enforcement agencies and first responders by employing unmanned autonomous systems (UAS) with high-resolution sensing and imaging capabilities for disaster remediation. Law enforcement agencies and first responders face significant challenges during an emergency event, such as a natural or anthropogenic disaster (earthquake, tsunami, fire, hurricane, tornado, flood, power or nuclear accident, act of war, or terror). One of the major challenges is acting decisively based on available information and considering human factors, making high-quality real-time situational awareness critical to effectively manage and safeguard civilians and in-field personnel. This project focuses on creating a smart emergency-response service system using UAS, both air- and ground-based system, equipped with state-of-the-art imaging, sensing, and communication systems to provide first response teams with high-quality, real-time information to act decisively and effectively via human-machine interactions. The objectives include: (1) develop and integrate UAS platforms, sensors, imaging and communication systems, and control and path planning algorithms to create a UAS-based smart service system for first response, (2) model the state of human and infrastructure during a disaster, identify the scene, and create access paths to safety, (3) test prototypes and pursue commercialization opportunities, and (4) educate the public and train first responders on the technology. This collaborative project involves faculty across four departments (mechanical eng., computer science and eng., electrical eng., and social psychology) at the University of Nevada, Reno and University of Nevada, Las Vegas, as well as experts from the UNR Seismology Lab and the local public safety sector of the Washoe County as system user. The organizations that support this project include the newly established Nevada Advanced Autonomous Systems Innovation Center (NAASIC) at UNR, the state-supported UAS program management office Nevada Institute for Autonomous Systems (NIAS), and the Nevada Industry Excellence (NVIE). These organizations have interest in industry-university partnerships, innovation, and commercialization.

**Intellectual Merit:** Applied research to create the UAS-based smart service system will focus on sensor data fusion, scene identification, modeling of the state of humans, infrastructure and their interactions, as well as the platform for testing and evaluating remediation strategies, communication schemes, and access path planning. Understanding of the system aspects will enable first responders and public safety command personnel to analyze and understand on-scene, active emergency situations through interactive, integrated data analysis and visualization, and give them the ability to sense, predict and act in a variety of disaster scenes and human socio-psychological conditions. In addition, the smart service system can provide data valuable for modeling and control strategies in environmental, behavioral science, sociology and anthropology, forestry and agriculture, meteorology, geology, seismology, mining, earth and atmospheric science, transportation, infrastructure resilience and extreme engineering.

**Broader Impacts:** The UAS smart service system for disaster remediation will provide first responders with high-quality, real-time data and information that can be used to act decisively, such as to guide/escort humans to safety, direct rescue crews to access trapped humans, and provide in-situ communication, medication, water, and food and power. This system will significantly impact the efficiency and effectiveness of the response process. The program will develop the requisite human infrastructure of graduate students in mechanical engineering, computer science and engineering, electrical engineering, and social psychology. Working together in the multidisciplinary team, students will be exposed to research outside of their respective discipline and to innovative opportunities for entrepreneurship. A successful smart service system will impact the operations of the public safety sector of Washoe County, and it could be adapted by similar organizations in other states. The education and training program will also expose undergraduate and K-12 students and first responders to new cutting-edge technology.
Enhanced Situational Awareness using Unmanned Autonomous Systems for Disaster Remediation

1 Project Goal, Motivation, and Objectives

The goal of this project is to enhance the situational awareness capabilities of law enforcement agencies and first responders serving distressed humans in disaster remediation, by employing unmanned autonomous systems (UAS) with high-resolution sensing and imaging capabilities. Law enforcement agencies and first responders face significant challenges during an emergency event, such as a natural or anthropogenic disaster (earthquake, tsunami, fire, hurricane, tornado, flood, power or nuclear accident, act of war or terror). One of the major challenges is acting decisively based on available information, making high-quality real-time situational awareness critical to effectively interact with, manage and safeguard afflicted civilians and in-field personnel. This project focuses on creating a smart emergency-response service system using UAS, both ground- and air-based system, equipped with state-of-the-art imaging, sensing, and communication systems to provide first response teams with high-quality, real-time information to act decisively within an effective socio-psychological framework.

Figure 1 shows the concept of the UAS-based smart service system consisting of air- and ground-based UAS supporting the efforts of first response teams for an example wildfire situation. UAS including small unmanned aerial vehicles and mobile ground robots will be equipped with sensors, cameras, and critical communication systems to collect on-demand information on the state of humans and infrastructure, to be used in real-time for decision-making, resource allocation and human-machine interactions.

![Diagram of UAS-based smart service system](image)

Figure 1. The UAS-based smart service system employing air- and ground-based UAS systems to support first response teams.

In Figure 1, during a disaster situation (e.g., a wildfire) UAS are deployed over the area of interest. The UAS is controlled by a command center, where a UAS pilot has direct communication with the emergency operations center (EOC). The communication between the UAS and the command center occurs over a direct link, and a nearby high-bandwidth data link.
will be put in place to provide high-bandwidth high-quality on-board sensors and cameras a link for relaying information for storage or off-line transfer to the command center and EOC. Data from air- and ground-based are interpreted by the EOC and communicated to first responders in the field, as well as to entrapped victims communicating with first responders or the EOC providing in-situ communication, medication, water, food, and power. In addition, the smart platform will also analyze and interpret data automatically in order to provide assistance to the user.

The research to create the UAS-based smart service system will focus on platform integration, sensor data fusion, scene identification, modeling of the state of humans and infrastructure, as well as the development and evaluation of remediation strategies, communication schemes, and access path planning. A prototype UAS system will be tested and evaluated in collaboration with industry partner Drone America and SpecTIR, public safety sector of the Washoe County and the Truckee Fire Department as smart system users, and experts of the Nevada Seismological Lab. The testing will occur during routine training sessions that are held annually by the Washoe Country Regional Emergency Operations Center (REOC).

The project objectives include: (1) develop and integrate UAS platforms, sensors, imaging and communication systems, and control and path planning algorithms to create a UAS-based smart service system for first response, (2) model the state of human and infrastructure during a disaster, identify the scene, and create access paths to safety, (3) test prototypes and pursue commercialization opportunities, and (4) educate the public and train first responders on the technology.

This collaborative project involves faculty across four departments (mechanical eng., computer science and eng., electrical eng., and social psychology) at the University of Nevada, Reno and University of Nevada, Las Vegas; and experts from the UNR Seismology Lab and the local public safety sector of the Washoe County; and partners include local companies Drone America and SpecTIR. This project is also supported by the newly established Nevada Advanced Autonomous Systems Innovation Center (NAASIC) and the Nevada Industry Excellence (NVIE), both of which fully support industry-university partnerships and innovation (see letters of partnership and support).

The team will leverage UNR Seismology Lab's extensive network infrastructure for data transmission (stand-alone high-bandwidth data-link stations). As test paradigms, the prototype UAS-based smart service system will be considered for in-field testing during frequent emergency events including wildfires that frequently erupt in the Reno/Tahoe area during the summer seasons as well as nuclear powerplant failures, and search and rescue operations in the surrounding areas.

2 UAS Efforts in Nevada and the Need for UAS for First Response

Nevada was recently selected by the Federal Aviation Administration to be one of six test sites to begin work on safely integrating unmanned aircraft systems (UAS) into the National airspace. For Nevada, officials predict thousands of high-paying UAS-related jobs, as well as $2.5 billion in economic impact— and $125 million in state and local tax revenue. Recently, through
Nevada’s Governor’s Office of Economic Development (GOED) Office, the Nevada Advanced Autonomous Systems Innovation Center (NAASIC) was created. This new center is located in downtown Reno, funded by the Knowledge Fund, and the focus is to spur research, innovation, and commercialization to advance knowledge-based economic development in Nevada. The proposed PFI:BIC project will work closely with NAASIC to explore commercialization opportunities (see letter of support).

Private sector partners include Drone America and SpecTIR (see letters of partnership). Drone America is a company located in Reno, NV, that manufactures and delivers amphibian and land UAS for humanitarian, civil, and military applications. They provide ISR (intelligence, surveillance and reconnaissance) flight services for government agencies (including, but not limited to Fire and Police Departments) and research/educational institutions. Drone America has agreed to provide a testbed unmanned aerial vehicle (UAV) platform for this project. SpecTIR, is a hyperspectral imagery and Geospatial Intelligence services firm providing sensor, remote sensing and data analysis products to domestic and international government and commercial clients. Their headquarters is located in Reno, NV. SpecTIR has strong interest in employing UAS for data collection and multi-sensor data analysis using their hyperspectral sensors and advanced data fusion techniques. They are particularly interested in applying the proposed technology for environmental baselining and remediation, and search and rescue operations to save human lives and ensure the safety of first responders. The company has participated in the environmental baselining of New Orleans after Hurricane Katrina and in SAR operations in support of Steve Fossett’s mishap in 2008. Hyperspectral imagery is a valuable data layer for enhancing situational awareness, improving planning operations along with near real-time tactical detection of manmade objects and survivors.

By minimizing human exposure to health and safety hazards, UAS systems have the potential to enhance the effectiveness and efficiency of first response teams. Such systems and their potential impact on civilian applications is being recognized both at the federal and state level. It is pointed out that First Responder disciplines include emergency medical services (EMS), fire, emergency management, explosives, hazmat, law enforcement, search and rescue, and communications.

3 UAS Smart System Development Plan

The key technologies of the UAS-based smart service system for first response are summarized in Figure 2. As shown, the data and information the system provides can be used by EOC and first response teams, for scene modeling, tracking of victims, access planning, damage assessment, education and training, and social studies.

The research to create the UAS-based smart service system for first response involves four major tasks: (1) develop and integrate UAS platforms, sensors, imaging and communication systems, and control and path planning algorithms, (2) develop models to predict the state of human and infrastructure during a disaster, identify the scene, and create access paths to safety, (3) test prototypes and pursue commercialization opportunities, and (4) expose students to innovation, educate the public and train first responders on the technology. Each major task involves
multiple sub-tasks to accomplish the objective of the main task. The project is expected to take three years to complete, the project timeline listing major tasks and the PI leading each task is shown in Table 1. The involvement of sensor personnel and other experts are discussed in Section 5. The details of each task are described below.

3.1 Task 1: UAS System Development: Platforms, Communication, and Visual Tracking (Lead Coordinators: Leang and Yim; 2-Years Duration)

This task focuses on developing the UAS system to support first responders, such as a UAV equipped with sensors, imaging system, and communication modules that function to gather information to be used by the EOC and first response team. Subtasks focus on the platform design and flight control system, communication network, and the technology for visual tracking of multiple objects.

UAV Platform, Navigation System, and Sensors Development (Leang, Yim, Doumanidis, and Shen)

(a) Develop fixed-wing UAV platform: This sub-task focuses on an air-based UAS vehicle, where the developed hardware and software tools will be implemented on a UAV. Drone America has agreed to provide the Muninn UAV base system (see partnership letter). The platform will house imaging, communication, servoing, environmental sensors, and flight control hardware developed by the PIs (see budget justification). A UAS command center to control the UAV will also be provided for testing. Figure 3 shows an example of the Muninn UAV, with a wing span of approximately 13 feet, length of 7 feet, payload capacity between 10-15 pounds, and maximum weight of 40 pounds. The endurance can be up to 24 hours on EFI engine, or up to 75 minutes on electric powered. The system is fully portable, can be assembled or disassembled in minutes, and easily fits into most passenger vehicles for transport. The platform is designed to operate from small improvised runways, or from a portable launch/recovery unit. Testing of the platform will be done at designated test sites in Nevada, with FAA approval and support from the Nevada Institute for Autonomous Systems (NIAS) (see letter of support).
NIAS was recently established by Nevada’s Governor’s Office to help oversee airspace operations for UAS.

The platform will be modified to support the instruments and sensors for this project. Dr. Leang, with expertise in UAS platform design and control systems will lead the efforts in developing the platform for this work. He will work closely with the Drone America engineering team and CEO Mike Richards, to ensure that the system meets all specifications and safety regulations. Communication between the UAS command center and the EOC will be created to allow the UAS operator and UAS data to be communicated to the EOC personnel to guide decision making and communication to first responders and the public. The team will also explore the development of a UAS ground vehicle by leveraging the mobile ground robotic platforms from the CSE department at UNR. Co-PI Bebis and his team will create a basic ground vehicle for testing and prototyping.

(b) Develop UAS for GPS-denied indoor search and rescue: Outdoor UAS such as a fixed-wing UAV typically relies on GPS for accurate position and velocity estimates, however, navigation through areas with GPS denied areas, such as in tight canyons or through collapsed buildings, caves, bridges, tunnels and other covered features necessitates an alternative approach. It should be noted that many emergency events can occur in GPS-denied locations whether they are indoor or outdoor. This also includes UAS system for monitoring and maintaining the processes inside of a nuclear power plant (NPP) containment structure to ensure that the plant stays within optimal operating conditions conducive to promote reliable and efficient power generation (see Figure 4(a)). This subtask will develop a UAS system which can function in GPS-denied environments such as inside buildings.

A small UAS platform for autonomous monitoring applications in GPS-denied disaster sites will be designed and built by co-PI Yim at the University of Nevada, Las Vegas (UNLV). An example is shown in see Figure 4(b). The proposed aerial platform will be equipped with chemical and radiation sensors/detectors to test the effectiveness of those sensors mounted on the aerial platform. The mobile nature of the robotic platform allows precise long-term measurements to be performed at desired locations. The objective is to construct, test, and deploy this autonomous monitoring system essential for long-term environmental monitoring, for example of new or aging NPP containment structures or other indoor GPS-denied disaster sites. Such a product would also be very attractive to potential customers around the world who are currently developing/constructing NPPs, and the next generation of nuclear facilities.
Additionally, the UAS platform will be designed and programmed to search for contaminants or other phenomena of interest based on cooperative sensing to localize their locations in the mock-up test bed in the laboratory. The following steps will be taken: (a) develop effective localization methods and (b) develop effective navigation strategy to maneuver. The localization problem will be addressed using optic-flow sensing technologies.

**UAS/EOC communications network development (Investigators: Sengupta, Bebis, Kent, and Smith)**

A robust and reliable communication system between the UAS and the first response command center is critical. This subtask will develop a UAS-specific communication system that can be integrated with the existing infrastructure. The objective is to provide a means of reliably connecting with the UAS, download data from the UAS, and communicate the information to the EOC or first responders in the field.

**(a) UAS Communication Network:** The future UAS networks are envisioned as dynamic spectrum access (DSA) enabled, interoperable and ubiquitous connected (anytime and anywhere) network with heterogeneous UAS nodes, networks and differentiated mission characteristics. The increasing availability of small UAS leads to the possibility of forming cognitive and temporary mission-centric networks using multiple UASs. Such networks have the potential to increase the range of UAS operation, adapt to the radio environment, provide improvements for communications capabilities, and ease communications-imposed operational constraints. Specifically, the multi-interface radios approach will be taken to connect reliably with each UAS within the grid. It is envisioned for an UAS radio platform to have multiple interfaces with different waveforms running on different access networks/spectrum bands. Since each waveform has unique characteristics and capabilities, it would be beneficial to share link information (e.g., topology, neighbor information, and linkPHY parameters) among different interfaces for better decision support in order to meet the broad spectrum of mission requirements.

**(b) High-Bandwidth Data Link Stations for High-quality UAS Data Download:** The Nevada Seismological Laboratory (NSL) operates its own managed flexible high-bandwidth microwave (speeds up to 100 Mb/sec) in western Nevada with coverage for the Reno-Carson City-Lake Tahoe corridor. NSL will establish data uplink capabilities for UAS based sensor data at 5 high-speed telemetry sites in the Reno-Tahoe area (see Figure 5).

The objective is to create two levels of capabilities; 1) ground based uplink to the microwave network locally from a UAS command/control system, and 2) download capabilities for UAS systems while airborne near a node/uplink location. Capability 1) will require landing the UAS system near the field command/control site then quickly uplinking large data volumes through the microwave to a UNR based data center for distribution to EOCs. Capability 2) will eliminate the need to land the UAS, remain airborne, and download large data volumes directly from the UAS to the microwave uplink. NSL will establish these capabilities and systems at the locations shown in Figure 5. This will provide UAS data uplink capabilities for incident command and disaster response/assessment in the Reno-Carson City-Lake Tahoe area. This is an existing microwave system enabled 24/7 in support of earthquake monitoring and is always available for data traffic. Multi-use capabilities currently include climate monitoring, fire cameras, and telemedicine support in Nevada and eastern California.
Computer Vision for Situational Awareness (Investigators: Bebis, Shen, Landers, Doumanidis)

To successfully deploy UAS in realistic environments, this subtask will address some key issues including (i) localization in environments where GPS is unavailable, (ii) detection of humans and other objects, and (iii) tracking. Industry partner SpecTIR has agreed to provide sensors for this work (see letter of partnership).

(a) Localization: UAS localization will be addressed by leveraging the team’s current work on rover localization for planetary exploration (funded by NASA). The main idea is using the horizon line to estimate the rover’s position and orientation. By aligning the detected horizon line in images obtained by the rover with the horizon line generated from Digital Elevation Maps (DEMs) of the same area, the localization problem can be solved. There are two critical issues to be addressed: first, how to reliably extract the horizon line in an image and second, how to compute the alignment transformation. A machine learning approach to extract horizon lines from images is proposed [1]. To compute the alignment transformation, the approach is to employ a global optimization approach based on Particle Swarm Optimization (PSO) which has shown great performance in more challenging pose estimation problems such as full DOF hand tracking [2].

(b) Detection: Finding human victims in post-disaster scenarios is one of the primary goals of any search and rescue operation. Moreover, responders in an emergency scene need to know their location as well as the location of other responders, victims, and potential hazards. Several approaches have been proposed for human detection in outdoor environments using UAS [3-6]. This is a challenging problem since body pose can vary widely. To address the issue of human detection (e.g., responders, victims etc.) in real-world outdoor environments, thermal and color
imagery will be used. Detected human positions will be geolocated and marked on a map which can be used, in the case of victims, to plan medical supply delivery during a disaster relief effort. The plan to use a pair of cameras, one thermal and a standard color camera, for human detection. Using the thermal image, potential human locations will be quickly hypothesized. To verify the hypothesized locations, the plan is to fuse the information from the thermal and color images and apply classification. For fusion, this work will leverage the team’s previous work on face recognition [7-9]. Different types of features and classifiers can be used to characterize and classify human bodies. A GIS database can be used to verify the validity of the calculated 3D locations while GPS can be used to test accuracy of the body’s geolocation.

(c) Tracking: This subtask will focus on exploiting the algorithms that were recently developed to enhance the performance of a UAS, particularly for tracking objects of interest in a disaster scene, such as first response vehicles, people in need of assistance, other nearby UAS, and propagation of disasters such as the spread of fires, etc. Recent developments in UAS have raised the importance of achieving dynamic adaptation in increasingly complex environmental perception/sensing for real-time self-detecting of surrounding traffic and infrastructure [10-12]. Among perception/sensing capabilities, visual sensing and feedback is one of the major approaches to improve the control performance of UAS [13], particularly, focusing on tracking multiple fast or slow moving targets or obstacles with arbitrary shape using rangefinders and cameras. Figure 6 displays a snapshot of visual tracking of multiple surrounded moving targets (vehicles) in a divided highway using the developed method and system. The preliminarily experimental tests show that the system can robustly track up to 32 targets in an update rate of 20 Hz. Thus, this innovation can be implemented in the UAS to enable adaptive cruise control, path planning, and intelligent collision avoidance for UAS. In addition, the results can be applied to coordinate multiple UAS in formation to cover and assess large disaster areas. For instance, it can be applied to wildfire monitoring for efficiently supporting first responders in wildfire damage minimization and remediation. The approach for tracking multiple objects can also be implemented to track multiple trapped human (targets) and mapping multiple victims’ locations, as well guiding/escorting multiple trapped human to safe locations or directions.

3.2 Task 2: Modeling, Scene Identification, and Anthropomorphization of UAS and Social Acceptance (Lead: Bebis and Murray; 2.5-Years Duration)

This task will focus on developing state-of-the-art approaches and methodologies for modeling the state of human and infrastructure during a disaster, scene identification using UAS, and creating access paths to safety. The objective is to create software tools, guidelines, and operations plans to help support first responder efforts and guide decision making. Subtasks focus on modeling of the propagation of disasters and scene identification, design of decision making approaches, and development of the First Responder Interface for Disaster Information (FRIDI).
Dynamic propagation of disasters monitored by UAS (Investigators: Doumanidis, Murray, Papa, and Kemmelmeier)

Accurate models of disaster propagation provide useful information on the dynamics of the situation and how resources should be allocated for effective countermeasures, taking advantage of UAS data to provide accurate, real-time information on the behavior of the disaster situation. Several natural or anthropogenic disasters, such as forest fires, earthquake collapses, tsunamis, floods and epidemics propagate on two-dimensional topological domains via dynamic percolation of random fractal patterns [14, 15], in clusters exhibiting statistical self-similarity across multiple dimensional scales. Percolation theory [16, 17] has addressed such propagation mostly on simple 2-D lattices, where nodes or sites are occupied, for example, by trees in a wildfire scenario with an occupancy probability, reflecting the density of vegetation (site percolation); or the nodes are interconnected via pathways with an activation probability, reflecting their connectivity density (bond percolation). Theory and simulation [12,13] have yielded the required critical densities or percolation thresholds \( p_c \) under which a disaster initiation event (e.g. fire ignition) will propagate. The wiggled, irregular form of the boundaries of such propagating clusters can be described by their fractal (Hausdorff) dimension \( H \), determined practically by image processing of cluster pictures (Figure 7) by box-counting algorithms [18]:

\[
H = \lim_{s_0 = s_0} \frac{\ln(N(s)/N(0))}{\ln(s_0/s_0)}
\]

where \( N \) and \( s \) are the numbers of boxes straddled by the pattern and the size of the boxes in Figure 7(a) and (b), respectively. The evolving size distribution of the clusters, i.e. the number \( n(\sigma) \) of clusters of characteristic size \( \sigma \), can be described by the size exponent \( \tau \) of a power law dependence: \( n(\sigma) = c. \sigma^{-\tau} \), where \( c \) is a dynamic factor.

Actual disaster propagation takes place on non-uniform and anisotropic terrains (e.g. due to directionality of wind) with percolation modes combining occupancy and connectivity. Therefore, a 2-D distribution of directional percolation threshold \( p_c(\mathbf{x}) \) over the full territory \( \mathbf{x} \) would need to be identified via image processing of pictures from UAV-transported sensors (e.g. visible or infrared cameras for wildfires). In practice, these dynamic maps will be analyzed in real time (through MATLAB ®) for the form and size of the clusters only at the perimeter of propagating boundaries (e.g. the fire front). Using the theoretical results, these will yield, via the fractal \( H \) and exponential \( \tau \) measures, initial estimates of the directional percolation threshold values \( p_c(\rho,t) \) on the cluster perimeter \( \rho \) over time \( t \). These critical values will be used for in-process dynamic Monte Carlo simulation [19] of the local front motion conditions, described by the normal outward propagation velocities \( v(\rho,t) \).
Finally, real-time modeling of the full disaster spreading distribution will be performed based on the local front propagation conditions above. To take advantage of the fractal clusters, a level set method (LSM) [20, 21] via fast-marching algorithms [22] will be preferred, to track evolution of the propagating front over the 2-D terrain of the disaster. LSM represents such moving boundaries as planar intersections of a dynamic scalar potential field $\varphi(x,t)$, moving as (Figure 8): $\frac{\partial \varphi}{\partial t} = - v \nabla \varphi$, where $v$ is the velocity at each location $x$ of the moving boundary, and the evolution of this potential field $\varphi$ describes the disaster propagation. This will be used for trajectory planning of the UAS, so that motion is controlled to track the disaster optimally, by mapping its boundary where it is needed most (i.e. highest $v$ areas) [23]. At a later stage, these techniques can also be used for optimal intervention of a UAV-based disaster remediation strategy based on the situational awareness tools.

**First Responder Interface for Disaster Information (FRIDI) (Investigators: Feil-Seifer, Bebis, Murray, Papa, and Kemmelmeier)**

This subtask will develop an integrated control and observation interface, called the First Responder Interface for Disaster Information (FRIDI), designed specifically for emergency management and law enforcement personnel. Robotic search and rescue (SAR) activities have been explored in domains such as surveying building rubble [24]. Robots have been shown to have a benefit for firefighters and other first responders in helping to address the challenges of disaster areas without visibility [25]. The FRIDI will be a GoogleEarth like top-down map interface but it will display near-live (images less than 24 hours old) surveys of the area as they are recorded from UAVs. This interface will also be used to task the heterogeneous robot systems.

(a) **Multi-modal sensor integrated data presentation:** Awareness of the environment is a key challenge to effective robot-assisted SAR [26]. Prior work has shown the importance of integrating visual information from incoming video with other robot sensor information [27]. Thus, a single map interface will be developed showing the positions and orientation of all robots in the scene along with all sensor and status information. Combining video data with other sensor data will allow operators to view the robots and task them without having to context-switch between video streams and other robot sensor data [26]. Prior work has shown that using such an interface with a combined air/ground robot team can be used to cut rescue times by a factor of 40% [28].

(b) **Low-workload interface for heterogeneous robot tasking:** In order to minimize operator workload as they control a large number of UAVs and ground robotic vehicles, a teleautonomous or mediated mode approach for control will be employed [29]. Wherever possible, autonomous control or low workload control will be preferred. This entails being able to task robots with navigation plans that the robot will carry out. This should minimize the necessary number of robot operators while utilizing operators to the best of their abilities. Prior work has shown that a point-and-click GUI interface is most efficient for maximum area clearance by SAR systems [30]. The user interface from industry partners will be combined with existing software for controlling the UAVs and ground robots used in this project.

(c) **Portable Interface to FRIDI:** The feasibility of developing companion software for mobile interfaces such as tablets and cellular phones will be investigated. This portable version of FRIDI
which can display the top-down interface described above but on hand-held devices used by first responders. Prior work has shown a positive response from first responders about the portability of the interface as well as the ease-of-use of the system in SAR scenarios [31]. A portable interface also raises the possibility of voice control/communication using this system.

This component of the work will heavily rely on the results of validation studies proposed in the next section.

**Anthropomorphization of UAS and Social Acceptance of the Technology for First Response (Investigators: Murray, Papa, and Kemmelmeier)**

Central to the effective use of UAS in emergency disaster events are 1) the acceptability of this technological assistance by the public, and 2) the ability of the human-technology interface to provide appropriate psychological first aid for assisting survivors of disaster. Underlying both issues is the anthropomorphism of UAS; that is, the attribution of humanlike mental capacities to machines. Research indicates that when machines are required to make critical decisions individuals who were previously led to attribute a thoughtful humanlike mind to the device are more likely to view the device as competent and trustworthy [32-34].

People respond to anthropomorphized devices with engagement and the same behaviors as when interacting with other humans [35]. Humanlike-behaving machines seem to induce some level of anthropomorphism in most people and increase the social influence of nonhuman agents [36]. However, machines that look too humanlike create discomfort and aversion [37]. This repulsion could impact survivors’ willingness to engage with the UAS during a disaster. The goals of this task are to 1) increase the public’s knowledge, awareness and anthropomorphism of the UAS that will be used in emergency and disaster events, and 2) examine the effectiveness of UAS in the decision making and delivery of psychological first aid by first responders to survivors in a disaster scenario.

**Research Activity to Support Goal 1: (a) Focus Groups Activity:** Homogeneous focus groups of six to ten community members (considering age, race/ethnicity, gender, and socio-economic status) will be moderated by the staff and graduate research assistant to determine base-line knowledge of the use of UAS and their implementation in disaster-related emergencies. An estimated six to eight groups (lasting 60 to 90 minutes each) will be needed before reaching the saturation point in new information presented. Groups will also discuss what they need to know about such programs, where they would welcome the presentation of information, and their level of comfort with various UAS-assisted support actions. They would also be shown renderings of various UAS and asked for input on what characteristics give the devices an acceptable level of humanlike representation which would make the participant likely to feel comfortable interacting with during a disaster. Focus group data will be analyzed and compared to existing research findings. Results related to humanlike representation and types of acceptable assistance will be shared with project members.

**Research Activity to Support Goal 1: (b) Community Awareness Campaign** Focus group results on knowledge of UAS, information on their use in disasters, and desirable venues for dissemination of information will be used to develop a community awareness campaign. The campaign will piggy-back existing educational efforts of Washoe County and its fire departments, as well as provide presentations at other venues. To increase anthropomorphism a
prototype UAS will be included for demonstration. Presentations are anticipated at fire department related school activities, local gathering places (e.g., community fairs, senior health fairs, malls), and large outdoor community events (Hot August Nights, Reno Rodeo, Great Balloon Races, Nugget Rib-Cook-off). At the end of the awareness campaign, an evaluation will be conducted through brief interviews at local sites (Dept. of Motor Vehicles office, grocery stores, malls) and will examine knowledge of UAS, information about their use in disasters (including local efforts), anthropomorphism, and types of acceptance of UAS in a personal disaster scenario.

Research Activity to Support Goal 2: Disaster Simulations and Psychological First Aid

UAS will be fitted with communication devices, including microphones and speakers, allowing for interaction with disaster survivors (supplemented with visual information when conditions allow). Activation of the UAS involves coordinated team activity, including the first responder who teleoperates the devices and the first responder who assesses the survivors’ situations and verbally interacts with them. Standard psychological first aid procedures for use in disasters have been developed by the National Center for Post-Traumatic Stress Disorder and the National Child Traumatic Stress Network. First responders utilize these types of protocols but it is not clear how the team coordination required for assisting the survivor via the UAS will impact the delivery of psychological first aid. Increased anthropomorphism by the survivor is also expected to enhance the effectiveness of this delivery system. During the project period, when the UAS is being tested in simulated disasters, we will provide opportunities to test its use with survivors who need rescue, support while waiting for rescue, or guidance and direction to safety. Observational data will be recorded and follow-up interviews with first responders and simulation survivors will be conducted by the researchers and graduate assistant. Results will be used to improve later simulations.

3.3 Task 3: Prototype Testing and Demonstration (Lead: Leang, Dorsey, Kenneston, Yim, Shen; 1.5 Years Duration)

This task will test the operation of the UAS platform (UAV donated by Drone America), outfitted with high-resolution cameras, environmental sensors and other hardware (donated by SpecTIR), and developed communication and scene modeling and object tracking software, to determine the feasibility of the smart service system for enhancing situational awareness. The testing will occur during routine training sessions held by the Washoe County Regional Operations Center, where initial field trials will take place during the later part of Year 2 and continue until the end of the project period. Senior Personnel Dorsey and Kenneston, from the REOC and Northern Nevada Regional Intelligence Center will assist in the testing phase of this project. They will provide input on how to best integrate the system into their operations.

Certificate of Authorization (COA) to deploy and test the UAV will be secured prior to any testing with the help of the Nevada Institute for Autonomous Systems (see letter of support). The test location will be decided through communication with NIAS and the Washoe County public safety office. Co-PI Kent and his team from the Nevada Seismological Lab will assist in managing data extracted from the UAV for use by the EOC and for disaster and scene modeling purposes.
Tests of the UAV developed by Co-PI Yim, where the UAV is designed to function in GPS-denied environments, will be done indoors in Yim’s lab. Additionally, similar tests will be done in PI Lenag’s lab, where the lab is equipped with a flying cage specifically designed for multi-rotor type UAVs.

The PI team will test the operation of the UAS systems to determine their performance and ability to gather data in the form of high-resolution videos, environmental information, and reliably communicating the information to a command station and the EOC. Other measures will be determined, such as flight time, power consumption, range, demands on pilots, deployment time, etc. This task will also lead to the development of operating instructions and protocols for the smart service system.

3.4 Task 4: Education and Training (Lead: Leang, Murray and Yim; 2.5 Years Duration)

To hone the effective interdisciplinary interaction presentation and communicate skills of the graduate students working on the project, the students will be encouraged to present their work at the UNR mechanical engineering seminar series and the interdisciplinary social psychology biweekly brownbags, starting in Year 2 and 3, as well as present their work to industry partners through NAASIC. Undergraduate students will be encouraged to present their work in the PI team’s courses as well as at the UNR Undergraduate Research Symposium, held annually in the spring semester. Faculty at UNR and UNLV will regularly highlight state-of-the-art research work in their class to help engage and excite students to learn the material. PIs will also facilitate the interaction among graduate and undergraduate students, enhance opportunities for the interdisciplinary scholarship that emerges, and assist the student group in preparing their work for submission to relevant integrative venues, such as the Society for the Psychological Study of Social Issues (SPSSI) conference. The PI team plans to provide tours to K-12 teachers and students on a regular basis, to show demonstrations of the technology developed in this project. The PI team will also highlight the results of this project during the College of Engineering Open-House event at the beginning of each academic year. A data management plan is attached with details on how the project data will be managed.

The PI team will also integrate the outcomes of this project into their respective courses. In particular, PI Leang, Bebis, Shamik, Feil-Seifer, Doumanidis, and Chatterjee teach courses that are part of the newly established UAS minor program through the College of Engineering. They will highlight the examples of the UAS system for first response in the courses they teach.

4 Intellectual Property and Commercialization Efforts

The possible intellectual properties resulting from this project including novel UAS platform designs, control and tracking algorithms, and scene identification and modeling software, in the context of disaster remediation. In addition, the entire UAS-based smart service system itself has the potential to be marketed and sold to first response teams and public safety organizations across the nation. A draft Coorperative Resarch Agreement is attached for dealing with potential intellectual property between the University and the two primary partners and others involved.
PI Leang led the efforts to establish the new Nevada Advanced Autonomous Innovation Center which is supported by the Nevada Governor’s Office for Economic Development. Thus, PI Leang and his are committed to working with NAASIC and leveraging the Center’s resources to help commercialize the developed UAS-based smart service system (novel platform designs, control strategies, and software) for disaster mitigation. Additionally, the PI team will work with Nevada Industry Excellence (NVIE) to leverage their services and expertise to connect with UAS industries to help expand and add more capabilities to the smart service system. NVIE regularly works with manufacturers in the state is supportive of this project and a partner with NAASIC.

5 Project Management

The project is expected to take three years to complete, and the project timeline listing major tasks are shown in Table 1 above. PI Leang will coordinate the overall project. The tasks, responsibilities of the core PI team, and the anticipated timelines for each task are listed above in Table 1 and the involvement of the Senior Personnel and other experts are summarized in Table 2. The PIs will communicate their efforts through a bi-weekly web-video conference meeting (such as Skype) for project review, planning, exchange of ideas, and brainstorming. Online project management software will be used to keep track of milestones, tasks, and deliverables. In addition, yearly in-person meetings will be held at UNR and/or UNLV. These visits are supported, in part, by requested travel funds (see budget and justification) and well as leveraging support from other sources, such as through NAASIC. The PI team and students will also plan to meet regularly at NAASIC and present their work at the Center with the hope of disseminating the project outcomes to other industry partners who visit the center regularly.

Table 1. Three-year project timeline, listing tasks and investigators involved.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Lead PI</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. UAS system development: platforms, sensors, etc.</td>
<td>Leang, Kent and Yim</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2. Modeling, scene identification, and access planning</td>
<td>Bebis and Murray</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3. Prototype testing, evaluation, and commercialization</td>
<td>Leang, Bebis, Kent, and Yim</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>4. Educational/training activities</td>
<td>Leang, Murray and Yim</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

6 Project Team

This project involves a diverse group of experts, including faculty from mechanical engineering (ME), electrical and biomedical engineering (EBME), computer science (CSE), civil and environmental engineering (CEE), and social psychology (SOP), as well as experts from industry and the local public safety sector. Table 2 lists the PI and Senior Personnel team and their responsibilities and involvement.

An Advisory Team consisting of Senior Personnel and industry experts will help guide the core PI team and development of the UAS smart system. In particular, the Team will provide oversight, help evaluate the integration of the system in the public safety system, and help mentor students involved in the project to innovation and entrepreneurship. The team will also
provide input on how to commercialize the technology and how to broaden its application in other areas.

Table 2. Core PI team and Senior Personnel and responsibilities.

<table>
<thead>
<tr>
<th>CORE PI TEAM AND RESPONSIBILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
</tr>
<tr>
<td>Kam K. Leang</td>
</tr>
<tr>
<td>George Bebis</td>
</tr>
<tr>
<td>Graham Kent</td>
</tr>
<tr>
<td>Colleen Murray</td>
</tr>
<tr>
<td>Woosoon Yim</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>SENIOR PERSONNEL TEAM, OTHER EXPERTS, AND THEIR INVOLVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name (Dept./Affiliation)</td>
</tr>
<tr>
<td>Indira Chatterjee (EBME/UNR); Haris Doumanidis (ME/UNR)</td>
</tr>
<tr>
<td>Graham Kent (Dir. Of Nevada Seismological Lab/UNR); Kenneth Smith (Assoc. Dir. Of NV Seismological Lab/UNR)</td>
</tr>
<tr>
<td>David Feil-Seifer (CSE/UNR); Shamik Sengupta (CSE/UNR); Yantao Shen (EBME/UNR).</td>
</tr>
<tr>
<td>Drone America engineer; Mark Landers (SpectIR)</td>
</tr>
<tr>
<td>Anthony Papa and Markus Kemmelmeier (Psychology, Sociology &amp; SOP/UNR)</td>
</tr>
<tr>
<td>Aaron Kenneston (Reno Regional Emergency Operations Center (REOC)) and Robert Dorsey (Northern Nevada Regional Intelligence Center)</td>
</tr>
<tr>
<td>Sandy Haslem (NVIE)</td>
</tr>
</tbody>
</table>

7 Dissemination

The research results will be disseminated through publication in high-quality journals (IEEE/ASME Trans. Mechatronics, IEEE Trans. Contr. Systems Techn., IEEE Trans. Robotics, Journal of Community and Applied Social Psychology, Disaster Management and Response, etc.) and presentation at 4-5 relevant conferences (American Control Conference, IROS, IRCA, and SPSSI). At the end of Year 3, the PIs agree to give at least two industrial seminars to highlight outcomes of the project, for example through the Nevada Advanced Autonomous Systems Innovation Center (NAASIC) and another through Nevada Industry Excellence (NVIE) organization, a state-supported non-profit focused on helping companies in the state of Nevada. In addition, the research results will also be posted on the project website, including videos and summaries of outcomes. The PI team will also host a workshop through the innovation center (NAASIC) to expose industry with interest in UAS systems. In addition, UAS for disaster remediation will be highlighted as a special exhibit in the T.L. Wells Nevada Discovery Museum across form the NAASIC headquarters and in partnership with UNR, to introduce the smart system technology to its numerous K-12 visitors and to educate the general public.

8 Prior NSF Support

No prior related NSF support.
9 References


