Table of Contents

1. Foreword
2. Scope, Interest and Motivation
3. Background
4. Existing Approaches and Deficiencies
5. Structure of Proposed System
   5.a. General Description
   5.b. Actors and Information Flow
      5.b.1 Actors
      5.b.2 IDEAS Behavior and Use Cases
   5.c. Cloud Platform and Processes
      5.c.1 Analysis and Deployment Server (ADS)
      5.c.2 Databases
      5.c.3 Operator Terminal Interface
      5.c.4 Mobile Client
      5.c.5 Processing and Big Data Component
6. Application Scenarios
   6.a. Traffic accident -- Common Emergency Scenario
   6.b. Night Time Surveillance of High Crime Areas -- UAV as a Proactive Actor
7. Implementation and Deployment Challenges
   7.a. Integration of the various components
   7.b. Regulatory Concerns
8. Social Considerations
   8.a. Privacy Issues
   8.b. Public Perception of UAVs
   8.c. Vandalism and Hacking of UAVs
9. Conclusion
10. References
1. Foreword

This paper is being written as a part of our class project in Management Science and Engineering (MS&E 238, Summer 2014) and is primarily driven by combined interest in information and UAV technologies. After studying the landscape through the lens of civilian assistance using UAVs and after an analysis of the references listed below, we determined that there are very few approaches where UAVs are employed in a civilian assistance role. Accordingly, we are proposing an integrated drone-based emergency assistance system.

We also want to take this opportunity to thank the teaching team of MS&E 238, Daniel Barreto, Davood Shamsi and Martin Valdez-Vivas for their feedback towards our project.

2. Scope, Interest and Motivation

Our team has a combined background in aviation/aerospace engineering, electrical engineering and computer science. This led us to focus our project on an information technology framework that capitalizes on the mobility and flexibility of UAVs. It is important to note that the focus and value of our project does not rely on the aerospace problem but rather on how to create a cloud-enabled platform that takes drones from their basic data and video recording roles and converts them into smart and proactive actors within emergency response scenarios.

While UAV technology is not new and has already been utilized in law enforcement efforts, it has not experienced a rapid evolution of supporting information technology infrastructure. Our team is interested on how cloud computing and big data can take UAV emergency response applications to the next level.

While we explored different applications in such diverse areas as retail businesses, precision agriculture, wildlife motoring or disaster relief scenarios the team’s belief is that emergency response situations constitute the perfect scenario to propose a cloud computing framework for advancing drone applications. Even though we initially considered a more complex application in the area of disaster relief, further analysis and inputs from the teaching team made us realize that a narrower and more innovative focus allows for better execution of a stronger proposal while paving the way for scalability of the system into broader and more complex applications.
3. Background

Unmanned Aerial Vehicles (UAVs) or “drones” have been traditionally used in data collection efforts such as geographic imagery. In recent years, the use of drones has rapidly expanded to civilian applications [1], [5], [6].

Given that law enforcement, civilian assistance operations and communications infrastructure are often stretched beyond capacity, we propose a cloud-based framework where drones not only collect data to enable improved coordination and decision making among emergency response entities but also perform actions executing autonomous or semi-autonomous instructions generated by the system as a result of acting upon data.

4. Existing Approaches and Deficiencies

We have not come across approaches that leverage the benefits of cloud computing and big data in emergency response scenarios. Unmanned Aerial Vehicles (UAVs) or “drones” have been traditionally used in data collection efforts such as geographic imagery. In recent years, the use of drones has also expanded to disaster recovery efforts. Such recent use of drones in disaster recovery includes a focus on coordinating rescue and relief operations [5], [6], [7], [8]. For example, Bahnik et al. propose the use of drones for crisis management using drones as mobile sensor platforms [5]. While Bahnik’s platform allows reporting of disaster parameters (e.g., spread of fire) in near real time, Bahnik does not provide for a cloud-based architecture that enables integration of drones into an existing civilian assistance infrastructure. Rather, the UAVs serve a simple reporting function.

Jovanovic [3] discloses a ground station control system for UAVs. Particularly, Jovanovic discloses software architecture for visualizing and controlling UAV’s data acquisition operations [3]. In Jovanovic, UAVs can receive remote-control commands from Ground Control Stations (GCS) in order to perform such actions as changing its direction of flight or directing a camera at a target [3]. While Jovanovic discloses a ground control system that may be used to control UAVs, Jovanovic does not disclose a cloud computing architecture or a big data framework. Another reference authored by Bahnik and Pilka [4] discloses a data management architecture for tele-operated UAV system. However in [4], the data from the UAV is usually collected and saved on a storage device of a PC board. These data are further used for post processing and analysis. Bahnik and Pilka do not store data in a cloud infrastructure let alone process it in the cloud. Thus, none of the
above references offer advantages provided by cloud computing and big data. It is important to note that the Bahnik and Pika reference was published in 2011 when cloud computing services such as Amazon Web services (AWS) were readily available and in stable operation. Despite this, the reference makes no reference to cloud computing and no reasons are provided for such exclusion. Nevertheless, the benefits of big data and cloud computing are abundant. Particularly, we believe that cloud computing can offer at the very least centralized data architecture enabling data sharing.

Lorencik [16] considers drones to be a form of robots and thus discusses them with respect to cloud robotics [16]. Lorencik acknowledged advantages of cloud computing and notes that cloud computing not only assists scalability but also is also advantageous from a cost perspective because you can only pay for computing and storage that you need. Lorencik also notes that the cloud can make drones lighter, smaller and faster [16]. This advantage of cloud computing would be very beneficial to IDEAS because it would help make IDEAS drones more agile thereby making them more suitable for dense urban environments that are often associated with 911 requests. Lorencik notes that one disadvantage of cloud computing is a loss of connection (e.g., network connection) with the cloud. We understand that this may be an issue. However, with IDEAS, we plan to address this deficiency by selecting cloud service providers with enterprise grade uptime rates supported by service level agreements (or SLAs). In addition, we envision secondary or backup autonomous landing systems on the UAVs in the event of an extended loss in connectivity. If the UAVs are fully autonomous, they may be able to fly themselves to a safe location or landing site even when a connection to the cloud is lost. This will improve civilian safety concerns associated with stalled UAVs.

Lorencik goes clearly beyond Jovanovic and Bahnik, by actually proposing a cloud based framework that uses Hadoop as a distributed file system and cloud based storage and compute nodes as shown in the figure from Lorencik below.
While Lorencik does propose a cloud based system to control a robot or a UAV, it is limited in that it is not focused on data sharing between different components or databases. For example, one may use Lorencik’s system to issue commands to a robot over the cloud, however the system does not appear to automatically collect diverse data from different databases to automatically issue instructions to the robots or even provide suggestions to a human operator who can issue the instructions to the robot. Furthermore, there is no feedback loop from the robots to the storage/compute nodes of Lorencik. Rather, the communication is one way, i.e., from the Lorencik’s storage/compute nodes to the robots. In a 911 or similar emergency assistance scenario, such a one way communication may not be beneficial because some feedback from the robots from real time 911 scenarios may be needed to provide an effective response.

Liu develops further on Lorencik’s cloud robotics approach to suggest that robots or UAVs can be connected together to form a networked robotic system that is able to accomplish more computationally intensive tasks [17]. Particularly, Liu proposes “a comprehensive distributed Cloud-enabled robotics framework for information fusion and provide a preliminary performance evaluation through a case study based on a video tracking application.” [17].
Figure 2. A Typical Scenario of a Cloud Robotic System [17].

Figure 2 from Liu illustrated above shows a cloud robotic system. Liu’s approach is simple - provide a single or unified web interface that accesses robots at different sites via a cloud computing infrastructure. Liu’s architecture provides elastic computing and storage resources on demand and schedules jobs or tasks according to its load balance policies. High availability can also be provided to desired clients [17]. While Liu proposes a networked robotics system, again similar to Lorencik there is no feedback loop from the robots to the storage/compute nodes of Liu.

Our proposed IDEAS framework endeavors to not only to significantly build upon these existing approaches, but also overcome some of their above suggested deficiencies. For example, and among other features, IDEAS provides a robust communication loop back from the UAVs to the IDEAS framework. Particularly, given that law enforcement, civilian assistance operations and communication infrastructure are often stretched beyond capacity, we propose a cloud-based framework where drones not only collect data to enable improved coordination and decision making among emergency response entities but also act upon the data autonomously or semi-autonomously.
5. Structure of Proposed System

5.a. General Description

Current emergency response systems rely heavily on operator actions before assistance is dispatched. We aim at translating the flexibility of UAVs and the advantages of big data and cloud computing into improved response times and streamlined operations, avoiding scenarios where resources are stretched to the limit.

IDEAS is based on pre existing phone and mobile data infrastructure, a cloud platform and Unmanned Aerial Vehicles (UAVs). The objective is to enhance existing emergency response systems by facilitating an integrated and coordinated response to civilian emergencies. The proposed system expands the spectrum of capabilities by using UAVs; the aircraft offer the flexibility of rapid deployment and reduced response times, will provide real-time information to improve situational awareness, and will have the capability of being autonomously commanded by the system. A high-level diagram of the system is presented in Figure 3.

Figure 3. High-level Architecture of IDEAS.
The system gets activated by traditional emergency -- 911 -- calls or via a mobile device client specifically designed to communicate with IDEAS. The mobile client is the preferred option for requesting assistance since it immediately provides additional information, increasing response effectiveness. More specifically, the mobile client provides IDEAS information such as live audio and video, Global Position System (GPS) coordinates, subscriber information and type of emergency (as selected by the user); this immediately triggers data processing to enable an insightful response. However, in the interest of serving the full consumer base, i.e. all civilians within the jurisdictional area, the system also incorporates phone call processing and accommodates for a similar response after an operator has provided missing information such as location of the emergency.

The next step after the team identified emergency response scenarios as an ideal area to advance UAV applications, was to define the expected behavior of the system. The resulting system-level structure is captured in Figure 4 as a Unified Modelling Language (UML) diagram. This representation breaks the system into well-defined use cases and serves as a starting point for implementation. However, multiple iterations of this UML diagram need not come as a surprise during subsequent design and implementation activities throughout which the system may be further refined.

The main innovations the team envisions IDEAS will bring to the emergency response landscape are:

1. Ability for civilians to request assistance via mobile app
2. Analytics that transform traditional emergency response infrastructure into smart autonomous or semiautonomous systems.
3. UAVs that are autonomously commanded by the system to provide real-time information where it is needed the most, including moving targets.

Two main design constraints the team kept in mind during the conceptual development of the system are:

1. The IDEAS platform is being conceived to cover a safety critical application and, as such, considerations for interfacing with emergency response operators and authorities are important, i.e. in cases where authorization is required before performing specific tasks.
2. In order to effectively serve the full civilian population within any given jurisdiction it is necessary for IDEAS to handle emergency response requests via phone, i.e. 911 requests.
5.6 Actors and Information Flow

Figure 4 shows the boundaries of IDEAS with a black rectangle; the system behavior is structured by breaking it into use cases. The seven types of external actors that are expected to interact with the system are also displayed.

The following subsections describe in more detail the roles of the different actors as well as the internal behavior of the system.
5.b.1 Actors

The expected actions from each of the different actors are as follows:

**Civilian - Mobile Client:** A civilian in an emergency situation, or witnessing an emergency scenario, and with access to the IDEAS mobile client is expected submit a request including as much information as the situation allows. The civilian is also expected to verify acknowledgement of the request via the mobile client and update authorities as necessary and when possible. Mobile client users must have previously accepted the terms of use and must have selected default settings to be used in emergency situations where circumstances do not allow to configure the individual request.

**Civilian - Phone:** Civilians in need of assistance and without access to IDEAS mobile client are expected to request help via traditional channels, i.e. using phone service to call 911. Information and details about the emergency are to be communicate to the operator as usual.

**911 Operator:** The operator tasks can be divided into three major categories,

1. The operator is responsible for assessing the legitimacy and authorizing assistance dispatch for requests made via the mobile app that IDEAS has determined as needing operator approval. For dispatch requests automatically initiated by IDEAS based on analytics, the operator is only expected to serve a supporting role for coordinating ground and manned aerial assistance if necessary.

2. For phone requests, the operator is expected to serve its traditional role of collecting as much information about the incident but also has the responsibility of providing those inputs to IDEAS via an IDEAS operator terminal application. The operator terminal offers additional flexibility such as the capability of dispatching immediate help even before incident information has been processed by IDEAS.

3. Setting up the system for specific modes of operation via the operator terminal. Specific system modes may include standby (default mode), No autonomous UAV dispatch, and UAV patrolling of specific areas.

**Proprietary UAV Base Station:** IDEAS is to be designed to communicate with a pre existing UAV base station in order to retrieve and store UAV data and to issue commands to the UAV, e.g. to modify its position.
**Real-time Traffic Data Source:** IDEAS is expected to interface with a traffic data source with the objective of assisting ground-based help in identifying best routes to and from the location of the emergency. This allows emergency response vehicles to get to the scene faster and to reach assistance centers, such as hospitals, in shorter periods of time.

**External Databases:** Multiple sources of data will assist IDEAS in making autonomous decisions. Information from 911 databases, government databases, mobile service provider databases, medical records and social media feeds is expected to be read and stored by the system.

**Emergency Response Ground Vehicle:** Vehicles providing ground-based assistance within a jurisdiction where IDEAS has been deployed will continuously transmit location information to the platform. This allows the system to determine the ground resources better positioned -- based on proximity -- to provide assistance in specific emergencies. In addition, emergency response vehicles are to be capable of displaying to their operators information transmitted by IDEAS such as best routes to reach accident scenes, hospitals with shortest travel times, estimated location of fleeing targets, etc.

### 5.b.2 IDEAS Behavior and Use Cases

A total of fourteen high-level use cases were identified to define the structure of IDEAS behavior. The use cases vary in complexity and range from complex “Big Data Analytics” and “ADS” processes -- which have the potential of further being decomposed into more granular use cases during the design process -- to more simple but critical process such as “Cancel Request”, “Wait for Authorization” or “Display Information”. A description for each of the use cases is provided below.

**Process Mobile App Request:** This process handles incoming mobile app requests and records information contained within the request such as mobile subscriber number, location coordinates, etc. It is also responsible for continuously reading streams of live data -- audio and video -- when the user has enabled such features. Providing status of the request back to the mobile app as well as updating the system with any new information provided by the user after the original request are also covered by this use case.

**Process Phone Request:** Requests made via traditional 911 calls are processed by this use case, which is complemented by the information provided by the “Answer Phone
Request" process. In this use case IDEAS automatically identifies caller information, records the call audio and awaits for operator inputs, including location of the incident and type of emergency; after sufficient information is available IDEAS invokes other use cases to execute operator commands -- e.g. dispatching a UAV -- and initiate analytics processing.

**Answer Phone Request:** This use case handles the 911 operator interface as necessary to support phone requests. Operator terminal screens designed for the operator to provide necessary inputs to IDEAS and for allowing the operator to dispatch immediate assistance, are displayed while this use case is being executed.

**Big Data Analytics:** This one of the most complex use cases and is to be further decomposed into lower-level use cases during the detail design of the system, here is where all the information is combined and processed, patterns identified, comparisons of the current emergency situation against external databases executed, etc. A conceptual explanation of the activities performed by this process is presented in Section 5.c.5, “Processing and Big Data Component”.

**ADS:** Another complex process, the Analysis and Deployment Server is in charge of consuming all input data -- including outputs from "Big Data Analytics" -- and translating it into actions, commands, and readable information. The ADS is explained in detail in Section 5.c.1.

**Provide Route Information to Vehicles:** IDEAS invokes this use case to provide operators of emergency response ground vehicles with best routes as determined by “Big Data Analytics”, where information such as location and type of emergency, traffic data, and location of hospitals is combined and processed.

**Command UAV to New Coordinates:** UAVs are expected to have enough flexibility to be the first component of the emergency response to reach the scene of an incident; for large jurisdictional areas UAVs could be strategically located across the region and ready for deployment while for smaller areas all UAVs could be maintained at a single location. This use case is executed within IDEAS when the system -- via either analytics or operator inputs -- has determined a UAV should be an immediate component of the response. The use case is also utilized by IDEAS as emergency situations evolve and the position of UAVs needs to be updated. Situations requiring the most extreme use of this process include incidents with fleeing targets where the system attempts to autonomously engage in pursuing them based on live data -- audio, video, images -- processing and continuous update of UAVs’ position.
**Wait for Authorization:** This use case is executed by the system to wait for operator authorization in cases where the “Big Data Analytics” processing of mobile app requests has not been able to autonomously determine the legitimacy of the request or the need of immediate assistance, especially in periods of operation where there is limited availability of resources.

**Cancel Request:** In situations where either “Big Data Analytics” or an operator determines a request to be illegitimate, or otherwise identify any valid reason to cancel a request, this use case is to be executed. The reasons for cancelling the request as well as the entity requesting the cancellation are to be logged together with all original request information.

**Display/Input Information:** This use case handles all tasks associated with displaying information to and collecting inputs from system operators. Execution of this process is expected to involve the use of multiple operator terminal screens containing different information fields depending on the tasks being performed and the progress of emergencies, e.g. request received, waiting for operator input, help dispatched, pursuing target, etc.

**Read External Database:** This is a generic use case with the purpose of covering all information read by IDEAS from a variety of external databases maintained by different entities such as 911 response center, mobile service providers, healthcare providers, law enforcement agencies, etc. As detail design of the system progresses and once the final list of all the databases to be used by IDEAS is identified, this use case is expected to be replaced by one individual use case for each of the different databases.

**Read Vehicle Location:** Ground emergency vehicles within the jurisdiction where IDEAS is deployed are to provide location information directly to IDEAS or via an external real-time source such as servers maintained by law enforcement agencies or fire departments. This use case covers the process by which IDEAS reads ground emergency vehicle location for subsequent consumption by analytics processes.

**Read Traffic Data:** IDEAS requires access to real-time traffic data for assisting ground emergency vehicles in identifying shortest-time routes to and from emergency scenes. The “Read Traffic Data” process retrieves real-time traffic data from a predefined reliable source.
**Read UAV data:** UAVs are a valuable source of data for IDEAS. The processing of UAV location, video and audio streaming and potential additional sensor data constitute a critical group of information upon which “Big Data Analytics” may base autonomous decisions. This use case covers the interface between IDEAS and the proprietary UAV base station in order to retrieve all data collected by the UAV.

### 5.c. Cloud Platform and Processes

**Figure 5.** IDEAS Cloud Architecture

#### 5.c.1 Analysis and Deployment Server (ADS)

Multiple ADS server instances may exist in the cloud. In other words, there is not one ADS server but a plurality of ADS instances that work in concert to process data (e.g., imagery) received from UAVs as well as data received from the terminals, mobile clients as well as government and law enforcement databases. In one example, an ADS server instance may be operated in the public cloud. An example of a public cloud is one that is provided by AWS. In an aspect, an ADS instance may receive location coordinates from a civilian’s cell phone or smartphone. The location coordinates may be received when the user dials “911” (or other emergency number) or selects an 911 app. The 911 app may allow the
user to press a single button to summon assistance. In some cases, however, the user may be asked to provide identifying information (e.g., a full legal name) prior to being able to request assistance through the 911 app. Returning to the operation of the ADS, once the location coordinates are received, the ADS may determine whether there are UAVs stationed or currently airborne in the vicinity of the received location coordinates. If there are UAVs that are indeed in the vicinity, the ADS may provide an indication of proximity of such UAVs to an operator terminal at a 911 dispatch center. The operator may then provide instructions to the drone to fly to the received location coordinates. This would be a “semi-autonomous” mode of operation of the UAV because some operator approval is needed before the UAV is dispatched to the received location coordinates. However, in an autonomous mode, the UAV may be automatically dispatched by the ADS to the received location coordinates. In this way the ADS acts as a “control layer” or “control stack” to the IDEAS big data because the ADS provides instructions based on the big data. In this way, the ADS acts like an entity to translate the analytics into instructions and readable information. The ADS serves as an engine orchestrating different instructional or control activities within the IDEAS framework.

It is to be appreciated that, in parallel with processing the location coordinates, the ADS also searches through databases in big data to determine whether (a) the location coordinates are associated with “fake” or “spoof” requests and (b) if the identifying information provided by the requestor is associated with previous malicious or spoof requests. If for example, either (a) or (b) is determined by the ADS to be true, then the ADS may provide an indication to an operator terminal at the 911 dispatch center even if the UAV is being operated in the autonomous drone mode noted above. In this way, spurious request may be handled by the ADS. Once the UAV is dispatched to the received location coordinates, the ADS continues to receive the location coordinates in real time as the UAV traverses airspace. The ADS controls the flightpath of the UAV based on a precalculated route to the received location coordinates. For example, the ADS may compute a path to the route and then generate a list of coordinates for the UAV to follow. If the UAV, deviates from the coordinates the flight path of the UAV may be corrected by the ADS.

In addition, the ADS also receives real time video imagery and sensor data from the UAVs. The video imagery and the sensor data may be processed by the IDEAS big data component before it is provided to the ADS. For example, the big data component may process the data further in order to determine patterns. The big data component may also use video processing techniques to identify activity between two or more consecutive video frames. In some aspects, if there are significant differences between the two or more video frames, then the ADS may provide a visual indication to the operator terminal at the
In addition, the ADS interfaces with government databases and 911 databases using secure data connectors given that IDEAS is implemented as a Virtual Private Cloud (VPC) infrastructure. Examples of the 911 and government databases are discussed further below.

An ADS instance may be a Linux (e.g., RedHat) platform. Each ADS instance may have its own storage that may be shared with other ADS instances. In some aspects, the ADS instance may use a version of the open-source Xen hypervisor. The Elastic Compute Cloud (EC2) instance may be assigned a static IP address. The static IP address may be used to launch a terminal to configure the ADS instance. The ADS instance may access the data stored in IDEAS big data. The ideas big data may be further processed as noted in the video frames example below.

Figure 5 illustrates a representation of the IDEAS architecture. The ADS communicates with the IDEAS big data, phones including smartphones as well as the UAVs. As shown in Figure 5, the UAVs also provide data to the ADS. This data may include real time video imagery, audio data, images. The ADS may provide control data (e.g., instructions to fly to geographic coordinates) based on analysis of the data received from the UAVs. Also, the ADS would receive data (e.g., geographic coordinates and 911 request information) from phones including smartphones. The receipt of such data may be via a touch tone telephone or a smart-phone application. The ADS may also interface with private databases such as a 911 database (e.g., 911 dispatch center database), government database, mobile operator terminals as well as operator terminals at the mobile center. These databases are described in detail in section 3.c.2. The ADS interfaces with the private databases over secure communication links which are encrypted communication channels. The encryption channels are established using public key cryptography. The encryption channels may use military grade encryption protocols such as Advanced Encryption Standard (AES).

The Advanced Encryption Standard (AES) is an encryption algorithm for securing sensitive but unclassified material by U.S. Government agencies and, as a likely consequence, may eventually become the de facto encryption standard for commercial transactions in the private sector ([http://searchsecurity.techtarget.com/definition/Advanced-Encryption-Standard](http://searchsecurity.techtarget.com/definition/Advanced-Encryption-Standard)). Thus, the communication between these private databases, which include sensitive or private data remains confidential during transmission between the private databases and the ADS. In one example, the private databases may store the data in an always encrypted form. The data is received at the ADS in its encrypted form and then decrypted by the ADS for further processing. In some cases, the decrypted data may be anonymized.
at the ADS so that it may no longer be used to identify a particular person. In this way the ADS may also ensure privacy of individuals.

Returning to Figure 5 above, we can see that the secure data connectors create a logical security perimeter that separates the private components of the cloud from public components. This effectively creates a virtual private network or VPC (http://en.wikipedia.org/wiki/Virtual_private_cloud). We chose VPC architecture for IDEAS because, allows private components to remain private and provides cost and scalability advantages of the public cloud. For example, if we were to implement the IDEAS framework in the near future, we could use a VPC solution provided by AWS. AWS would allow us to host scalable applications in the cloud while maintaining secure connectivity to the private 911 datacenters. Other advantages of VPC include, the ability to set data traffic policies that control flow between the public and private components.

5.c.2 Databases

Referring to Figure 5, the IDEAS framework includes integration with 911 databases, government databases and operator terminals. The 911 databases may include data regarding phone numbers from where 911 calls are made, the frequency of calls associated with a number and the geographic location coordinates associated with the received calls. In some cases, the 911 database may also store addresses associated with the phone numbers. When a phone call or 911 app message is received at the ADS, the geographic location coordinates or phone number associated with the call are used by the ADS as a key to retrieve an address associated with the number, the ADS may then check whether the address has been associated with spoof requests or accidental 911 calls. If the address is such an address, then the ADS may provide a notification to the operator terminals in the 911 dispatch center or mobile terminals in 911 vehicles. The government databases may include data associated with citizen information. For example, when a residence address is provided to the government database, then a name of residents living at the residence address may be retrieved by the ADS from the government database. In addition, the government database may also store information regarding criminal history associated with individuals.

The databases may be SQL or even NoSQL databases. However, it is more likely that these databases are legacy SQL or any other type of relational database. It is possible that the throughput of data received from these legacy government databases may be slower than what is needed. Thus, these databases may need to be tuned for performance using database optimization techniques and by balancing network traffic, disk throughput
and CPU time. For such optimization, collaboration with the government agencies may be needed to enable effective interfacing between the ADS and the private databases. As noted above, IDEAS utilizes a VPC architecture that allows for both public facing and private components, when privacy laws change these private databases may be transitioned, in their entirety or in part, to the public cloud. When these databases are transitioned to the public cloud, they may be migrated from a traditional SQL architecture to a NoSQL architecture. One example of a NoSQL architecture is AWS DynamoDB. DynamoDB is a fast, fully managed NoSQL database service that makes it simple and cost-effective to store and retrieve any amount of data, and serve any level of request traffic (http://aws.amazon.com/dynamodb/). Its reliable throughput and single-digit millisecond latency make it a good fit for IDEAS architecture where time to provide assistance is a critical parameter.

5.c.3 Operator Terminal Interface

The operator terminal interface is an integrated interface that enables the operator to monitor the status and control the various components of the IDEAS framework. It alerts the operator whenever manual intervention is required and provides real time updates about the status of components (UAVs, ground vehicles, etc).

It has the following main functions:
1. Display alerts and real time updates to operators.
2. Provide ability to set high level system modes (e.g. standby, patrol, etc).
3. Provide interface to input information to IDEAS and dispatch assistance.
4. Provide interface to take full manual control of various components, if necessary.
5. Change the settings of various components.

The terminal is expected to display the location of UAVs, summary of UAV data, location of law enforcement vehicles and summary of data provided by civilians. This allows the operator to monitor the system and intervene when necessary.

5.c.4 Mobile Client

The mobile client application empowers civilians by allowing them to be active participants and helping law enforcement agencies. The mobile application allows civilians to report emergencies as well as provide useful information about emergencies to law enforcement agencies. The application allows users to report the location of emergencies and provide real time video/audio and photographs. As the IDEAS framework becomes widely
deployed, this application can come preinstalled in smart phones so that almost all users have it by default.

![Figure 6. Mobile Client User Interface Mockup.](image)

To report an emergency, the user can select the type of emergency and provide more details. Figure 6 shows a possible implementation of the user interface of the application. When reporting an emergency, the user is given the option to capture video, audio or photographs (or upload these from the phone). Depending on the default settings of the application, the location of the emergency is automatically recorded. If not, the user can manually specify the location. The user is also presented with an option to call a 911 operator to report the emergency. If the user makes a call to 911 operator using the application, the location coordinates are automatically recorded and sent to the 911 operator. The mobile application data is integrated with the big data framework of IDEAS and this allow real time analysis of the information. The big data framework can, for example, automatically detect multiple users reporting the same emergency and use information from all the users to get a more complete picture.
After reporting the emergency, the user is given real time updates about the emergency. The user’s request is validated (by doing some sanity checks to detect bogus requests). If analysis of the user’s request shows that more information is necessary, the user is informed that a 911 operator will call the user for more information. A 911 operator is provided with the information given by the user and connected to the user. If analysis detects that the user’s request is a duplicate of an event already reported, it is tracked along with the original event. The user is kept updated about the status of UAV, status of law enforcement vehicles, etc (see Figure 6 for a sample user interface implementation of this).

After the user has reported an emergency, he/she can provide updates to the event. The user is allowed to provide streaming video/audio or take photographs or describe what is happening using text. This information is analyzed in real time and corroborated with data from UAVs and other sources. Location of the mobile phone is automatically tracked (unless disabled by the user) to help the UAV and law enforcement agencies locate the accurate location of the emergency. The user also has the option to call a 911 operator to report any important updates. If the system detects multiple calls to 911 operators to provide updates for the same emergency, the users can be requested to provide input via text instead. This will help streamline 911 operator resources and minimize the need for manual intervention for every call.

The default settings of the application enable location tracking. The users are also opted-in to a notifications mechanism by default. In addition to notifying the users about emergencies they reported, this notifications mechanism keeps the users informed about emergencies and situations in their vicinity. The users are also provided the option to opt-in to calls from 911 operators or law enforcement agencies when they are in the vicinity of an emergency (this option is disabled by default). This allows 911 operators or law enforcement officers to call civilians in the vicinity of an emergency to obtain valuable information. This is useful if law enforcement officials are unable to reach the area quickly enough. In such scenarios, civilians along with UAVs can help with information gathering.

5.c.5 Processing and Big Data Component

The IDEAS framework is data driven and uses big data analytics for real time decision making as well as long term insights. As described in Reference [11], big data is characterized by 5Vs - Volume, Variety, Velocity, Value and Veracity. IDEAS framework results in a large amount of data (Volume) generated from different sources in different formats (Variety). The data is generated at a high rate and decision making needs to
happen in real-time (Velocity). The data provides important information about events and allows making intelligent decisions and valuable insights (Value). Data is transmitted from source to ADS cloud infrastructure using secure channels (Veracity). All these make big data technologies appropriate for IDEAS.

Figure 7 shows the various components involved in generation, storage, analysis and consumption of data in the IDEAS framework. The following sections will describe these components in more detail.

Data Sources
IDEAS framework uses data from the following sources:

UAVs:
UAVs generate a lot of real time data that is transmitted to ADS infrastructure through a secure channel. This includes:

- Logs and sensor related data:
  This data provides information about the operating status and health of each UAV (location, battery status, temperature and other operating conditions). This information can be used to decide the next course of action for the UAV. The UAV operation is automated as much as possible (with the option for manual override) so that the control center only needs to issue high level commands instead of controlling every motion of each UAV.
  Depending on the sensors that are present on the UAV, information can also be gathered about the environment in which the UAV is operating. This can be used for recording ambient temperature, detecting smoke and fire, gas leak detection, motion detection, etc.
Video data:
UAVs provide a real time video stream of events at the location of interest. Real time analytics can be performed on the video to get valuable information (eg. capture the
license plate information of vehicles involved, detect motion of vehicles and people, detect presence of weapons, detecting fire, detecting traffic in areas). Doing these analytics on video on a real time basis can make law enforcement agencies take swift and effective actions, which can solve cases much quicker and save lives. Detecting motion of vehicles will allow the UAV to follow the vehicle while capturing a video stream. Detecting traffic conditions on various roads can help the IDEAS framework to guide police and ambulance to the point of interest in the quickest possible way.

- **Audio data:**
  UAVs can capture audio at the location of interest. This is useful to detect gunshots, or signs of people in danger. Analyzing this information in real time and alerting law enforcement officials can help them take swift action.

- **Photographs**
  The UAVs can capture photographs of the location of interest which can prove to be valuable evidence for solving cases. Real time analysis can also be performed on the photographs to look for presence of weapons, fire or other objects or persons of interest.

**Mobile clients:**
The mobile application running on mobile devices of civilians provide a channel for civilians to communicate with law enforcement.

- **User generated content**
  In case of an emergency, alerts can be sent to the mobile applications of all users who are in the vicinity of the emergency. The application provides an interface for users to capture video, photos or send messages to law enforcement. This user generated content, along with the content generated by UAVs can help the IDEAS framework get a better idea of the situation on the ground. The user generated content is also processed in real time and analyzed for useful information.

- **Auto generated data**
  The mobile applications also automatically send information, like speed at which the user is travelling, to the ADS server, which can help the IDEAS framework get a better idea about the traffic on different roads.
Data from Internet:
- Social media analytics
  In addition to data generated from the mobile application, there is usually lot of relevant and useful information available on social media. Analyzing social media data from areas of interest can provide useful insights.
  Social media analytics can also enable the system to detect threats and alert law enforcement agencies.

Data Storage
The data from the various sources can be either structured data or unstructured data. The data is stored in a cloud based distributed storage. Unstructured data is stored in raw format as much as possible after necessary filtering to ensure that no information is lost. This provides the option of going back to the data and analyzing it again looking for dimensions that were not analyzed during real time processing of the data.

Analysis Layer
The analysis component performs real time and long term analytics on the data. For real time analytics, stream processing technologies will be used. For other analytics MapReduce like batch processing technologies will be used.

The analysis component uses information from various government databases (DMV vehicle and driver records, criminal records including photos of criminals, FBI terrorist databases, etc) to look for matches.

The real time analytics output is used for control of UAVs, providing updates and alerts to mobile applications, providing information to the operator terminal and law enforcement agencies.

Longer term analytics can be used for doing analysis after the emergency has subsided. This can be used for improving operational efficiency of UAVs and other components. It can also help detect patterns between current events and past events and events in other geographies. Mobile client usage data can help improve the mobile user experience and help make the application more effective. Analytics can also help analyze resource allocation during emergencies and help improve operational efficiency.

With enough data, predictive analytics can be performed to predict events before they occur based on trends. This can help law enforcement prevent emergencies and be better prepared when they happen.
6. Application Scenarios

The two application scenarios described below illustrate the benefits introduced by IDEAS as well as how the different components of the system react under specific emergency situations. The application scenarios are described using a predefined list of sequential actions.

6.a. Traffic accident -- Common Emergency Scenario

In this application scenario we explore how IDEAS improves the response characteristics for one of the most common types of emergency response requests.

Scenario description: Traffic accident including injured civilians.

Initial Operator Input: Not applicable. The operator and the system are standing by to respond to emergency requests.

Emergency Request From Civilian: The traffic accident is reported via mobile client. The request includes coordinates, notification about injured civilians, and phone number from where the request originated.

Request Capture: IDEAS captures the request via the “Process Mobile App Request” use case. Information contained within the request is stored.

IDEAS Input Data: Input data consists on the information contained in the initial request, real-time traffic data and information from external databases.

Analytics Processing: “Big Data Analytics” processes the information contained within the mobile request and identifies no concerns with its legitimacy. The phone number is compared against mobile service providers’ databases to determine the identity of the individual submitting the request; once the identity is determined it is run against all relevant external databases – for the purpose of this example it will be assumed that no relevant background is found in external databases.

ADS Data Consumption and Commands: The “ADS” use case consumes information from the request as well as results from “Big Data Analytics”; this translates in an immediate autonomous activation of emergency response mechanisms.
**Operator Actions as Prompted by the System:** IDEAS has identified no concerns about the legitimacy of the request and has initiated the response autonomously. The operator continues to stand by – or answers other requests. IDEAS will prompt the operator if inputs are necessary.

**UAV Dispatch and Actions:** The ADS dispatches a UAV to monitor the accident by executing “Command UAV to New Coordinates”. In this scenario the UAV only serves a monitoring purpose. It can also provide insight about the severity of the accident to emergency response crews before they get to the scene.

**Ground Assistance Dispatch and Actions:** The ADS alerts ground crews and provides the optimal route to the scene of the accident – as determined by “Big Data Analytics” – via the “Provide Route Information to Vehicles” use case.

**Transfer of Parties Involved (Victims, Criminals, etc.):** Injured civilians are rushed to the nearest hospital as determined by IDEAS. The system also provides optimal route information.

### 6.b. Night Time Surveillance of High Crime Areas -- UAV as a Proactive Actor

IDEAS will be designed to offer the capability -- via operator terminals -- to specify patrolling areas for UAVs. The sequence of events taking place in a hypothetical scenario where the patrolling capabilities of UAVs are utilized is described below.

**Scenario description:** High-crime urban area with low light conditions. No emergencies reported.

**Initial Operator Input:** A 911 or law enforcement agency operator defines the UAV surveillance area. This information is captured by IDEAS via the “Display/Input Information” use case and subsequent IDEAS tasks make extensive use of the “Command UAV to New Coordinates” use case.

**Emergency Request From Civilian:** Not applicable in this scenario.

**Request Capture:** Not applicable in this scenario.
**IDEAS Input Data:** UAV data including audio, video and infrared imagery is continuously read by IDEAS via the UAV base station. This is achieved through the “Read UAV Data” use case.

**Analytics Processing:** The “Big Data Analytics” use case continuously processes UAV data in order to identify pre-established patterns such as violent noises and motion. Infrared imagery and audio are specially useful in low-light conditions. By combining infrared imagery and audio signatures, IDEAS can identify gunshots and violent interactions between individuals. For the purpose of this application scenario, it is assumed that a UAV was flying sufficiently high to cover a wide area and while doing so captured infrared imagery of a gunshot, information confirmed by a matching audio signature ([http://bbn.com/products_and_services/boomerang/](http://bbn.com/products_and_services/boomerang/)).

**ADS Data Consumption and Commands:** The ADS -- via IDEAS execution of the “ADS” use case -- continuously consumes analytics summary data. As soon as the ADS receives analytics information identifying a gunshot, it commands the UAV to track the thermal signature closest to where the gunshot originated, i.e. the thermal signature of a potential suspect; this is made possible by continuous processing via “Big Data Analytics” and “Command UAV to New Coordinates”.

**Operator Actions as Prompted by the System:** Aside from ground vehicle operators, there is minimal dispatch center operator interaction under this scenario. The operator may be monitoring the situation to provide further configuration inputs to IDEAS (such as assisting in refining or correcting the UAV suspect tracking path).

**UAV Dispatch and Actions:** Not applicable in this scenario. UAV previously dispatched.

**Ground Assistance Dispatch and Actions:** In parallel with the other activities described under “ADS Data Consumption and Commands”, the ADS communicates the UAV coordinates in the form of route information to ground law enforcement vehicles. This is achieved by execution of “Provide Route Information to Vehicles”; the information is continuously updated via the same use case as the UAV continues to track the thermal signature of the potential suspect.

**Transfer of Parties Involved (Victims, Criminals, etc.):** Once the subject is visually identified and captured by law enforcement personnel IDEAS provides route information to the nearest applicable law enforcement facility.
7. Implementation and Deployment Challenges

7.a. Integration of the various components

There are several components involved in the IDEAS framework (UAVs, government databases, mobile clients, 911 infrastructure, etc). Integration of all these components, especially the legacy components like government databases, could be challenging.

This can be addressed by using a phased approach to the introduction of the IDEAS. IDEAS could be first introduced as a pilot system with a few UAVs that can operate independently. ADS and big data software would run on limited cloud infrastructure and there be limited operator terminals that can be used to manually send inputs to various law enforcement agencies. As more components are integrated into IDEAS, more functionality can enabled.

Governments are beginning to adopt cloud computing and big data technologies (e.g. CalCloud, Federal Cloud Computing Initiative). This is expected to ease the integration challenges with IDEAS. In addition, there are several tools available to help integrate legacy databases with big data solutions (e.g. IBM data integration tools http://www-01.ibm.com/software/data/integration/products.html). Using Virtual Private Cloud (VPC) infrastructure allows IDEAS to integrate private components, while allowing them to remain private.

7.b. Regulatory Concerns

Federal Aviation Administration (FAA) released a fact sheet recently (http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14153), which describes the current procedures for getting approvals to use UAVs for law enforcement operations today. It says “There are currently two ways to get FAA approval to operate a UAS. The first is to obtain an experimental airworthiness certificate for private sector (civil) aircraft to do research and development, training and flight demonstrations. The second is to obtain a Certificate of Waiver or Authorization (COA) for public aircraft. Routine operation of UAS over densely-populated areas is prohibited.”

Based on these regulations, today local governments will need to obtain a Certificate of Waiver or Authorization (COA) from FAA before deploying the IDEAS framework.

President Barack Obama signed the FAA Modernization and Reform Act of 2012 (https://www.govtrack.us/congress/bills/112/hr658/text). According to this, the FAA is charged with developing a plan “for the safe integration of civil unmanned aircraft systems
into the national airspace system as soon as practicable, but not later than September 30, 2015”. This plan is expected to have rules and regulations for use of UAVs for law enforcement operations also.

UAV regulations are expected to evolve as UAVs are more widely deployed and this is expected to be less of a concern going forward.

8. Social Considerations

8.a. Privacy Issues

Government surveillance of citizens has become a topic of national debate, especially after revelations about the National Security Agency (NSA)’s surveillance programs that were put in place after the terrorist attacks in September 2011 (see this article http://www.theverge.com/2013/7/17/4517480/nsa-spying-prism-surveillance-cheat-sheet for a description of some of the surveillance programs). There are concerns that a lot of the surveillance is unconstitutional. This will be a concern with any use of UAVs by law enforcement because UAVs can enables government agencies to secretly track, monitor and profile residents.

While our proposal mainly deals with using IDEAS framework for emergency assistance, the framework could also be used for surveillance. We expect that the IDEAS framework would be covered by privacy rules and regulations that are currently in place for data collection and analysis using government satellites, CCTVs and similar methods. For example, Reference [14] describes the best practices, rules and regulations for using CCTVs. These regulations would apply for data collected by UAVs as well as data collected from mobile applications. In the wake of recent privacy concerns, privacy and surveillance standards, rules and regulations are expected to evolve. We expect these rules and regulations to cover the IDEAS framework also.

8.b. Public Perception of UAVs

UAVs have traditionally been associated with military operations but they are increasingly being used for civilian operations. There is evidence that public perception of UAVs is changing. According to a report on UAVs by AeroSpace Industries Association (Reference [15]), a survey by Monmouth University shows strong public support for civilian UAV operations in the United States. Of those surveyed, 80 percent approved of use of UAVs in search and rescue missions and more than 60 percent approved of their use for border
patrolling and tracking down criminals. If privacy concerns are addressed through strict rules and regulations, and people are made aware of the advantages of the IDEAS framework, use of UAVs for IDEAS is likely to be viewed favourably by the public.

8.c. Vandalism and Hacking of UAVs

UAVs need to be capable of operating in various weather conditions so that the value of IDEAS can be maximized. In addition, measures must be taken to deal with vandalism and hacking of UAVs.

UAVs are likely to be vandalized by criminals (who want to stop law enforcement monitoring). People could also try to bring down UAVs for fun, to be able to capture them and to hack them. To deter people from these activities, there should be adequate penalties on people caught doing these activities. Since UAVs transmit their data in real time, they could provide clues on what caused them to stop operating normally. UAVs can also be equipped with tracking devices so that law enforcement agencies can track them down easily if they stop operating. There should also be security features in UAVs that should automatically shut down most of the functionality once damage is detected. This will minimize the damage hackers can cause with captured UAVs.

9. Conclusion

Through our paper we have proposed an innovative framework that not only expands the use of UAVs into civilian applications but also leverages advantages of cloud computing and big data to accomplish this in an effective manner. The cloud computing and big data resources that we have described in our paper are commercially available through reliable vendors. Accordingly, hurdles to gather computing resources and data storage resources are not insurmountable. While we acknowledge certain integration challenges with legacy and private government databases, our proposed framework has incorporated cloud computing paradigms such as virtual private cloud, to address such challenges. At the time this paper is being written, the Federal Aviation Administration (FAA) has not yet fully approved the use of drones in commercial operations. We do not see IDEAS as a commercial operation, but rather a government supported initiative that seeks to improve lives of citizens in the domain of civilian emergency assistance. Over time we envision a significant shift in the perception of UAVs by governments. We hope that this shift, coupled with the integration of commercial UAV operations into the national airspace system, will allow IDEAS to become a reality in the near future.
10. References


[12] IBM Big Data Architecture design patterns

[13] IBM Smarter Planet Public Safety

(http://www.dhs.gov/xlibrary/assets/privacy/privacy_rpt_cctv_2007.pdf)


doi: 10.1109/SAMI.2013.6480950


IDEAS logo created using free resources and editor at
http://www.graphicsprings.com/start-your-logo