A UAV-Cloud System for Disaster Sensing Applications

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***Abstract*—The application of small civilian unmanned aerial vehicles (UAVs) has attracted great interest for disaster sensing. However, the limited computational capability and low energy resource of UAVs present a significant challenge to real-time data processing, networking and policy making, which are of vital importance to many disaster related applications such as oil-spill detection and flooding. In order to address the challenges imposed by the sheer volume of captured data, particularly video data, the intermittent and limited network resources, and the limited resources on UAVs, a new cloud-supported UAV application framework has been proposed and a prototype system of such framework has been implemented in this paper. The framework integrates video acquisition, data scheduling, data offloading and processing, and network state measurement to deliver an efficient and scalable system. The prototype of the framework comprises of a client-side set of components hosted on the UAV which selectively offloads the captured data to a cloud-based server. The server provides real-time data processing and information feedback services to the incident control centre and client device/operator. Results of the prototype system are presented to demonstrate the feasibility of such framework.**

Keywords—UAV; cloud; scheduler; wireless network; video communication

I. INTRODUCTION

Disasters, whether caused by nature or man-made actions, have had a devastating impact on the quality of human life across the world. For example, global climate change and extreme weather have resulted in more frequent and severe flooding events in both the UK and worldwide. Statistics from the United Nations Office for Disaster Risk Reduction show that there were 3455 major flood disasters between 1980 and 2011. The data contained in their report also highlights a steeply rising trend in the frequency of major flood events [1]. Similarly, large scale man-made disasters have also occurred frequently in recent years, e.g. oil spill accidents [2]. In order to deal with the challenges posed by such events, researchers in both academia and industry have increasingly turned to the use of UAVs which have been shown to provide large area coverage and real-time high-quality data acquisition capabilities, as well as have low capital costs and fast deployment time [3].

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Although UAV-based projects represent the cutting edge in disaster management technology, there are several existing more traditional disaster observation and monitoring approaches, such as the use of ground observation vehicles, satellites and man-piloted airplanes. Ground observation vehicles can respond quickly but their coverage and geographical accessibility are limited. Additionally their view of an area may also be restricted by the presence of buildings, debris or natural features [4]. Satellites provide large coverage and fair resolution, but accuracy and the time taken to position them before data can be acquired may restrict their usefulness in time-critical disaster situations [5]. Man-piloted airplanes can react quickly and cover large areas but are not suitable for applications where there is a high risk to human beings (e.g. radioactive disasters) or where repeated/prolonged coverage is needed, they are also costly to maintain. Other specialized monitoring systems designed for specific disasters do exist but are not discussed due the space limitation of this paper.

UAVs appear to be a potentially promising choice that can enhance traditional disaster surveillance systems and overcome the limitations of traditional methods. In particular, small civilian UAVs have the advantages of good coverage, downward facing high definition cameras, low costs and fast deployment. However, the limited onboard battery power and computation processing capability of small UAV's can limit their effectiveness. In order to address these challenges, a recent study proposed the idea of integrating computing cloud infrastructure with a UAV system [6]. Another enhancement proposed in [3] is UAV cooperation so that the work load can be shared by multiple UAVs which improves efficiency and increases capability. These innovative techniques have inspired two questions. Firstly how to effectively utilize the large volume of data generated by UAVs during disaster management operations and secondly the overall design and implementation of a UAV-cloud framework. This paper aims to fill this gap in knowledge by proposing a novel service-oriented computing framework which forms a UAV-cloud system.

During the recovery period from natural disasters, telecommunications infrastructures may be destroyed or severely impaired, requiring UAV communications to be routed over ah-hoc networks provided by the tactical radio

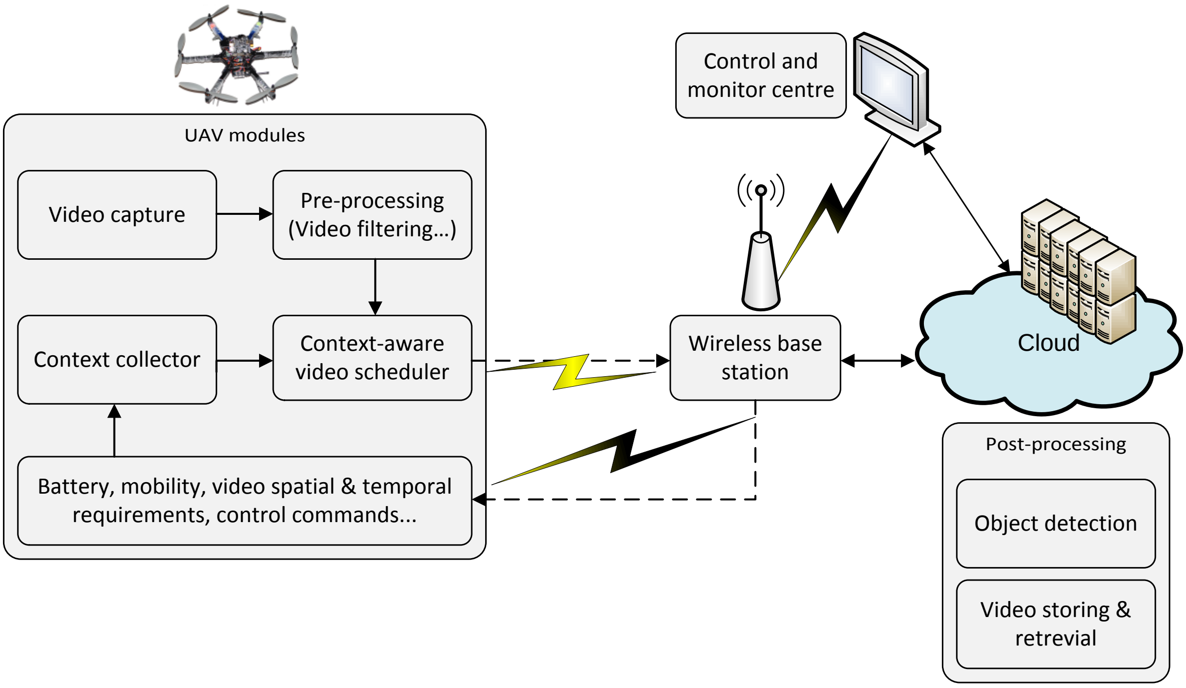

Fig. 1. The UAV cloud framework.

networks of civilian or military responders. In such challenging deployments, these tactical networks often suffer from impairments such as lost, intermittent or limited connectivity and are typically described as disconnected, intermittent and limited (DIL) environments.

Generally, the introduction of cloud computing can overcome the resource limitations of UAVs via data offloading. However, the offloading process is not without cost as, for example, offloading large volumes of data can seriously drain the energy resource of the UAV and consume a large proportion of the available network bandwidth. Existing work on mobile cloud for smartphone applications has proposed the use of customized algorithms to determine the strength and availability of network infrastructure before offloading [7]. These algorithms have inspired the design of the UAV-cloud framework in this paper which describes the key UAV, computing cloud and network components of the proposal scheme. The need for network state measurement is even more acute in DIL tactical network environments than in mobile networks supported by robust and redundant commercial infrastructures and is an important component of the proposed scheme.

A client-server configuration delivers two broad sets of techniques. The client is hosted on the UAV, which collects video data and context information from its hardware. It also has a context-aware video scheduler that selectively offloads captured data to the cloud based on contextual information. The server, hosted within the cloud infrastructure, listens for incoming traffic from the client. When meaningful data is received, the server provides valuable services such as computationally-intense signal processing algorithms for object identification, and communicates the outputs from advanced processing services to the control centre.

The rest of this paper is organized as follows: Section II describes disaster sensing scenarios and challenges; Section III introduces design goals and assumptions; Section IV provides an overview of the whole framework; Section V presents the prototype system; Section VI discusses the current design and future developments, and Section VII concludes this paper.

II. PROBLEM STATEMENT AND CHELLENGES

The deployment of small UAVs for collecting critical information in disaster areas has been an innovative but challenging task. Specific challenges include

- Ground areas may have been severely changed or disrupted by the disaster. The infrastructure may have been damaged or destroyed. Disaster scenarios may also be highly unpredictable and complex.
- UAVs have battery constraints which substantially limit their flying time, communication capability and computational capacity.
- The UAV may be required to communicate over DIL tactical network environments where network state awareness must be factored into any algorithm which decides when data can be transmitted to the cloud-based server.
- The overall disaster sensing task has stringent requirement on timeliness. For example, the first task

following a major disaster is usually search and rescue, which would require image/video information collected and processed in a timely fashion, preferably in real time.

- The mobility pattern of UAVs directly affects the collected data and the performance of image processing algorithms. Specifically, the quality of acquired data may vary during the flying time. If all data were to be transmitted to the base station, unnecessary power and bandwidth would be consumed.
- Object detection and other disaster applications require high quality image and video information. UAVs should be able to adjust their flight patterns to optimise data quality.
- Intelligent video capturing and processing tools can significantly improve the quality of decision making in disaster scenarios.

Similar challenges can be found in mobile communication networks where mobile devices are restricted by their power and computational capability. Researchers have developed joint smartphone and cloud systems to deal with such problems by applying mobile cloud computing and virtualization [7]. Initial results have indicated significant reductions in energy consumption of mobile phones and reduced processing times using mobile cloud. One study [8] suggests that it is not always efficient to connect to a cloud. The deployment of UAVs in disaster management has much higher complexity than using smartphones on mobile networks. Additional factors such as time, flight path, task management and data processing, all require specific innovative solutions.

Inspired by the aforementioned studies, this paper proposes a UAV-cloud framework to address the challenges within disaster sensing scenarios. To further enhance the framework, a context-aware scheduler which systematically adjusts video and data transportation based on a pre-processing algorithm forms part of the design. Fig.1 shows the block diagram of the whole system. To the best of our knowledge, no similar innovative framework has been previously proposed or designed.

III. DESIGN GOAL AND ASSUMPTIONS

The design of the proposed UAV-cloud framework is based on the following assumptions which are already true or can be implemented with reasonable effort:

- *Efficient on-board video pre-processing algorithms.* In the prototype system, the image histogram distribution metric is used to distinguish between frames for a specific mission. As a relatively cost-efficient image processing technique, histogram distribution is calculated for every captured video frame in the implementation. More advanced algorithms can be researched and implemented in the framework for improved performance.
- *Frame-based video data segmentation and communication.* In the prototype system, one frame per second is used as a representative sampling rate, thereby reducing the amount of data offloaded to the cloud.
- *Sufficient UAV onboard storage*. The storage should be large enough to store all video data captured during the whole deployment time. This should be easily attainable given current solid state drive technologies.
- *Adequate wireless communications between UAV, wireless base station, cloud and the control centre.* The installation of pre-processing algorithms on the UAV can filter out a large number of unnecessary frames, with the remaining critical frames reliably transmitted to the cloud. Commands from the control centre should also be transmitted to the UAVs reliably.
- *Performance enhancement through cloud computing.* The performance and scalability of the cloud and thus the whole system can be enhanced with reasonable effort.

IV. UAV SENSING FRAMEWORK ARCHITECTURE

The block diagram displayed in Fig. 1 provides a higher level view of the framework. From the design perspective, it can be split into two categories: client and server. The modules within the client mainly include a context collector, a context-aware scheduler, and a video capturing and pre-processing unit. The server hosted in the cloud mainly manages video retrieving, object detection, other data mining algorithms and data storage. It provides an interface through which the control centre can access processed information, aiding decision making by human operators. The client and server are connected through wired and wireless networks.

A. Client components

The three major modules of the client work as follows. The video capture and pre-processing unit collects video data, stores them in the on-board hard disk, and carries out simple pre-processing. The video data is then fed to a context-aware scheduler that also receives data from a context collector. Critical UAV system information including battery level, mobility, and location information, as well as key information received from the control centre including video spatial & temporal data and control commands etc. are collected and passed to the scheduler. Armed with contextual awareness and network state awareness, the scheduler can make intelligent decisions about video data transportation by considering all of the available contextual information. A more detailed explanation of each component’s functionality is given in Section V where the prototype implementation is outlined.

B. Server components

The server components are hosted in a computing cloud which supports virtualization and scalable resource allocation in order to satisfy power hungry, computationally-intense data processing requirements. The main modules of the server include a video retrieval unit and data storage algorithms which underpin a range of data mining and signal processing services. The server listens for client information and retrieves video data for deep processing with results (e.g. detected potential targets), sent to the control centre for evaluation by a human operator. The cloud also provides scalability and easy-configuration features such as the update of post-processing algorithms.

C. Communications

The client, server and control centre are supported by two types of networks: wireless and wired connections. UAVs and the control centre are connected by a wireless base station. The control centre has wired/wireless connection to the cloud which exchanges data with the wireless base station through a wired network. In each case data may, in disaster recovery situations, be transmitted over tactical radio networks exhibiting DIL environment characteristics. Whilst not explicitly considered in this pilot study, the choice of communications model may suit a service oriented environment where the reliability of communication is achieved through a web service middleware.

V. PROTOTYPE SYSTEM IMPLEMENTATION

In order to test the proposed framework and demonstrate its design features, a prototype of the proposed architecture has been fully implemented. A picture of the UAV is shown in Fig. 2 and a screenshot of the client processing result is shown in Fig. 3.

Fig. 2. 3DR Hex-Rotor UAV Platform.

The video capture unit of the client records video data which is stored on an on-board hard disk. It then selects one frame from each frame set (a pre-defined sampling period e.g. every n^{th} frame) captured and sends it to the pre-processing unit. The pre-processing algorithm calculates the histogram distribution of the image. This current histogram image is then sent to the context-aware scheduler.

Simultaneously, the context collector polls the on-board sensors and systems to collect UAV real-time mobility patterns, battery power level, spatial coordinates and network state metrics.

These data are fed into the context aware scheduler together with the output data from the video pre-processing stage. The scheduler then determines if the frame should be sent to the cloud for more rigorous analysis or not.

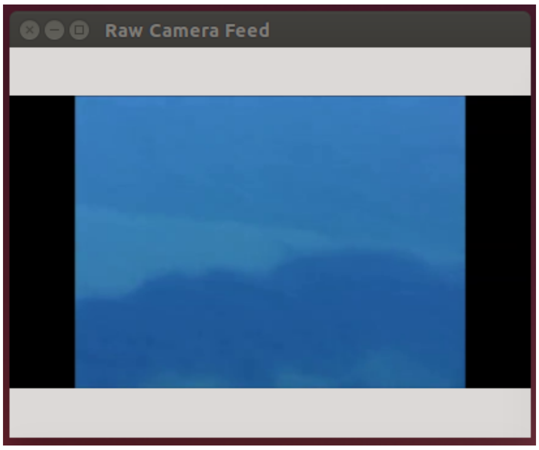

Fig. 3. A screenshot of the processing results at the client side.

Firstly, the scheduling algorithm checks the UAV status information and ensures it has enough residual power to transmit data. If this is true, it then checks the mobility pattern of the device to ensure the acquired data is of sufficient quality or contains objects of interest. The third step of the algorithm is to compare the histogram distribution of the current frame with those computed on previously acquired frames of the same mission. If a significant difference is detected, the network state information is evaluated to determine if it will be possible to transmit the frame within a timeframe which would make it useful for real-time evaluation. If there is sufficient network availability and capacity, the frame will be sent to the cloud for further processing.

The server components are hosted in a virtual machine supported by a computing cloud. The video retrieval unit constantly listens for incoming data and reconstructs the video data prior to passing it to the post-processing algorithm. In the pilot implementation, the post-processing component consists of a single service designed to detect oil spillage in marine environments [9]. The server also stores received video data for future processing by other services that may be requested by operators or incident controllers when additional information is needed to support a command decision. The server also provides an access interface to the control centre. The pilot implementation described in this paper provided limited server functionality. Future research will investigate more accurate detection algorithms, communication protocols (between control centre and UAV), automatic annotation techniques of historical UAV data (to facilitate further data mining) and implement the most suitable ones for deployment. The final implementation may also create a service oriented middleware to manage services available to operators and incident commanders. A screenshot of the server side processing results is shown in Fig. 4. In order to show the design features of the framework and the efficiency of this architecture, an experiment using practical UAV video data has been conducted within the current prototype system. We compared the number of video frames transmitted from the UAV to the cloud before and after the adoption of the framework. Fig.5 shows the result. From the figure, we can see that approximately only 10% of raw video data was sent and processed by the scheduler, which demonstrates the efficiency of the proposed pre-processing and context aware approach.

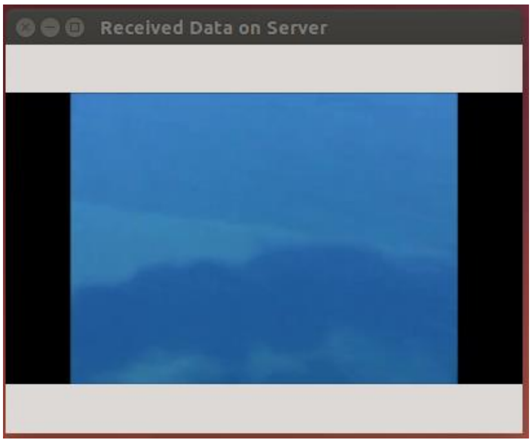

Fig. 4. A screenshot of the video results at the server side.

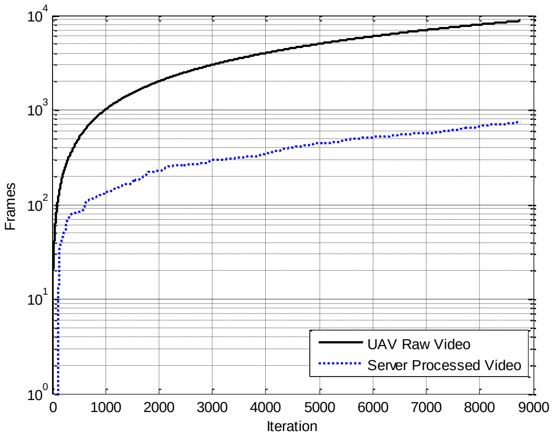

Fig. 5. Comparing of the change of the number of frames through the adoption of the proposed framework.

VI. Discussion and Further Work

The current prototype system does not address the impact of network impairments, which is important to the performance of the whole system. For example, the scheduler should also include network state metrics in its decision on transmission. If the wireless channels between the UAVs and base station can support high data rates, higher definition video data and more frames can be sent to the cloud. If the channel quality is stringent, only critical frames and messages should be exchanged in the network.

Both the algorithms for pre- and post-processing, hosted in the UAV and cloud respectively, are fairly simple and should be improved in terms of efficiency and detection performance. Future work will enhance these algorithms, test the scalability of the cloud and improve the overall framework.

Disaster scenarios are usually unpredicted and cover a large geographical area. To support emergency services would require coordinated actions from multiple aerial vehicles and/or ground robotic systems. The proposed UAV-cloud framework will be extended for such application scenarios and include the essential multiple-agent cooperation and data sharing mechanisms.

VII. Conclusion

This paper proposes a UAV-cloud framework for disaster sensing applications under the condition of DIL networks. Its major components include client units hosted by the UAV onboard system and server units hosted by the remote computing cloud infrastructure which provides service-oriented resource support. In order to save energy and improve disaster sensing performance, the onboard client filters acquired video data and only offloads those frames that are essential to the cloud for advanced processing. The cloud runs sophisticated power-hunger algorithms, e.g. object detection, and reports to the control centre. The proposed framework is suitable for the scenarios which have a large amount of video data requiring real-time or close to real-time processing which is essential in disaster related applications.

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