# Unmanned Aerial Vehicle based flash flood monitoring using Lagrangian trackers

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## ABSTRACT

Floods are the most common type of natural disaster, and causes thousands of casualties every year in the world. In particular, flash flood events are particularly deadly because of their short timescales. Classical sensing solutions such as fixed wireless sensor networks or satellite imagery are either too expensive or too inaccurate to detect them. In this article, we show that Unmanned Aerial Vehicles equipped with mobile microsensors could be capable of sensing flash floods in real time for a low overall cost, saving lives and greatly improving the efficiency of the emergency response. We present an ongoing implementation of this system using 3D printed sensors and sensor delivery systems on a UAV testbed as well as some preliminary results using simulation data.

## 1. INTRODUCTION

Floods are one of the most commonly occurring natural disasters. They have caused more than 120,000 fatalities in the world between 1991 and 2005 [1], and are a major problem in many areas in the world. Be-

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cause of the global warming which causes more extreme weather events around coastal areas, floods are expected to become more frequent in the next decades. As an example of their, the catastrophic 2009 Jeddah floods claimed hundreds of lives and caused hundreds of millions of dollars of property damage. Most flash flood fatalities are caused by drowning [6], which could be avoided by providing accurate flash flood maps to the population in real time.

Though rain monitoring systems have been used for flood prediction and estimation before [2], flood caused by extreme rains cannot be accurately predicted with these systems, as flood propagation models require a large number of parameters which are difficult to know beforehand.

Current sensing systems are either too expensive to deploy or too impractical to be used in the context of flash flood monitoring. A new form of sensing known as *Lagrangian sensing* makes the use of mobile (floating) sensors, and has been recently investigated in the context of hydrological sensing in [8]. Lagrangian sensing is very promising for large scale sensing, or on demand sensing, as it requires minimal infrastructure.

This project proposes the use of UAVs as a platform for Lagrangian flood sensing using microsensors [3]. In this framework, a set of UAVs would drop small disposable wireless sensors over the areas to monitor. These wireless sensors would be buoyant, and would be carried away by the flood. UAVs will receive signals from these sensors, and will map the extent of the flood, transmitting back this data in real time to a fixed ground

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station for processing (in particular estimation, forecast or inverse modeling) and dissemination to the civil authorities and to the public.

The rest of this article is organized as follows. Section 2 introduces the concept of UAV-based Lagrangian sensing for real-time flash flood monitoring, which is illustrated on a simulated example in section 2.2. We then present a high level system overview in section 3, and an ongoing implementation using a remote controlled plane equipped with an autopilot, a computer on module and a 3D printed microsensor delivery system launching microsensors.

## 2. PROPOSED FLOOD SENSING SYSTEM

#### 2.1 System overview and architecture

In our proposed system, a set of UAVs equipped with an array of droppable (disposable) microsensors is sent over the area to monitor, *i.e.* an hydrological basin on which a flood could occur. The UAVs would only be launched whenever flooding could occur, based on rain forecasts over the region, or based on other direct measurements (for instance electronic rain gauges). While it is relatively difficult (mainly due to the uncertainty in the hydrological and atmospheric models) to predict the occurrence of floods, predicting rain events that could lead to floods can be done easily from weather satellite data.

The Lagrangian microsensors would emit a unique ID (similarly to an active RFID tag) periodically as soon as they are released from the aircraft, until battery exhaustion. After their fall, these microsensors would settle on the ground, and can either remain static, or be carried away by a flood, being designed to be relatively insensitive to wind due to their high mass to surface ratio. After dropping the transmitters, the UAVs would track their evolution using directionnal antennas (for instance a conformal phased array placed on the underside of the wings). Multiple UAVs can be used to collaboratively monitor a given area, enabling a real-time map of the position of these transmitters to be quickly established.

The complete system is illustrated in Figure 1.

#### 2.2 Flash flood detection simulation

Flooding is well modeled by the shallow water equations (SWE) [4], which are obtained by integrating the Navier Stokes equations in depth, assuming that the horizontal scales are much larger than the vertical scales. This assumption is valid during flood events, as the horizontal scales are in the order of kilometers, while the vertical scales are at most a few tens of centimeters. A further simplification, known as the Diffusive Wave Approximation to the shallow water equations (DSW,[7]) is a simplification used to model flows where the vertical



Figure 1: Proposed UAV sensing system architecture.



Figure 2: Open loop forward flood simulation. In this simulation, we consider a terrain representative of the Jeddah hydrological basin in which catastrophic floods occurred in 2009. As can be seen, the high rains create multiple runoffs (among which a primary runoff in the main valley) that carry the sensors away.

momentum is small relative to the horizontal, which is also the case in flash flood events.

We simulate the evolution of the water level in a physical domain representative (in terms of declivity, Manning coefficient and total elevation drop) of the area that was flooded during the 2009 Jeddah flash floods. This simulation covers a of 24 minutes (1500 seconds), and is shown in Figure 2. We assume that a series of sensors are scattered by UAVs between times t=0 to t=300s. As can be seen from this figure, the sensors are flushed downstream by the flow, and move by approximately 400 meters in a 300 seconds time frame. Given the typical positioning errors of the UAV (GPS) and its antennas, such a motion would be detected by the UAV within one minute.

## 3. CURRENT IMPLEMENTATION

To build this system in practice, we selected large re-

mote controlled aircrafts that we equipped with an autopilot (Ardupilot 2.6), a Gumstix Overo Earth Computer on Module and a 3D printed microsensor delivery system. Since we could not find commercial microsensors suitable to the task of sensing, we also designed the microsensors using 3D printing.

# 3.1 UAV

The UAV airframe is a C17 remote controlled airplane in which the radio receiver of the airplane has been replaced by a Ardupilot autopilot module. One of the advantages of the C17 airframe is its large wingspan (1.4 m) and powerful electric motors (1 kW) enabling a top speed of 72 kph at a mass of 2.9 kg. Its payload capability is around 400 grams, which is sufficient to house the electronics and the sensor delivery system including the microsensors (which have a negligible mass). The code of the autopilot was modified to enable more reliable takeoffs and landings (the airplane is not hand launched and has to land on a road section). The complete system is illustrated in Figure 3.



Figure 3: Current UAV system.

#### 3.2 Microsensors

In order to accelerate the implementation, the microsensors have been manufactured using discrete components, and encapsulated in a 3D printed enclosure made of ABS plastic. We used a system-on-chip solution equipped with an Intel 8051 microcontroller, and a 868MHz RF transceiver. The package is manufactured by Texas Instruments under the name CC1110. The Intel 8051 MCU has 128 bytes of memory (IRAM) and 4 KB of programmable ROM. The transmission power of the RS transceiver can be configured to various settings. It is currently set at 0.01 mW, which gives a range of a few hundred meters. Sending packets at 10Hz and powered by a classical 3V Lithium coin cell

battery, a microsensor is expected to have an autonomy of a few hours.

A set of microsensors together with the circuit board is illustrated in Figure 4.



Figure 4: Microsensors used for this study.

Future microsensors will be based on printed circuits in paper, such as the sensors described in [5]

## 3.3 Microsensor delivery system

The microsensor delivery system consists of a distribution wheel, a frame and a 5V Kiatronics 28BYJ-48 stepper motor driven by a Texas Instruments ULN2003V12 driver chip. The driver chip is connected to four GPIO pins of the Ardupilot autopilot module. The distribution wheel contains 8 slots, The microsensor delivery system is similarly has similarly been 3D printed in ABS plastic to speed up the development of the system. The total weight of the microsensor delivery system including the microsensors is less than 200 grams, and the complete assembly is illustrated in Figure 5.



Figure 5: Microsensor delivery system.

## **3.4** Preliminary results

To validate the concept, we performed a test using the UAV platform described above in conjunction with the Lagrangian microsensors, to test their range and the location error arising in practice. For this test, we used an omnidirectionnal 868 MHz antenna onboard the UAV to detect a microsensor dropped on the ground. The flight took place south of KAUST campus on February 13, 2014 and its total duration was 120 s. A photo of the UAV in flight and the RSSI of the signal detected by the UAV (whenever detection occurred) is shown in Figure 6. As can be seen from this figure, the variations in RSSI are quite significant and can allow the microsensors to be approximately positioned, though more accurate positioning can be achieved with phased-array antennas, which is the subject of future work.



Figure 6: Top: UAV in automatic flight mode during final approach. Bottom: UAV trajectory and measured RSSI.

# 4. CONCLUSION

In this article, we presented a new UAV-based flash flood sensing system capable of monitoring extended geographical areas during high rain events, detecting the onset of flash floods and providing estimates of the flood propagation in real time. This system relies on Lagrangian microsensors that are inexpensive enough to be dropped and disposed of after the sensing. Current Unmanned Aerial Vehicle platforms are not capable of flying during very harsh environmental conditions. Our objective is thus to develop UAV platforms and low level control schemes capable of reliable flight in or below the cloud layer. We are also investigating high level control schemes for optimal multi-agent path planning that minimizes the time required to detect if a flood is present or not.

#### ACKNOWLEDGMENTS

We would like to thank Nathan Collier (KAUST, EE) for performing the flood simulations, PhD students Mohamed Abdelkader (KAUST, ME), Mohammad Shaqura (KAUST, ME) and Wael Alheadry (KAUST, EE) and MS student Omar Habib (KAUST, ME) for their help setting up the UAV system.

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