Proposed Tethered Unmanned Aerial System for the Detection of Pollution Entering the Chesapeake Bay Area

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ABSTRACT

This paper is based on a proposed unmanned aerial system platform that is to be outfitted with high-resolution sensors. The proposed system is to be tethered to a moveable ground station, which may be a research vessel or some form of ground vehicle (e.g., car, truck, or rover). The sensors include, at a minimum: camera, infrared sensor, thermal, normalized difference vegetation index (NDVI) camera, global positioning system (GPS), and a light-based radar (LIDAR). The purpose of this paper is to provide an overview of existing methods for pollution detection of failing septic systems, and to introduce the proposed system. Future work will look at the high-resolution data from the sensors and integrating the data through a process called information fusion. Typically, this process is done using the popular and well-published Kalman filter (or its nonlinear formulations, such as the extended Kalman filter). However, future work will look at using a new type of strategy based on variable structure estimation for the information fusion portion of the data processing. It is hypothesized that fusing data from the thermal and NDVI sensors will be more accurate and reliable for a multitude of applications, including the detection of pollution entering the Chesapeake Bay area.

Keywords: Failing septic systems, remote sensing, environmental monitoring, multispectral, UAV, NIR, thermal IR

1. INTRODUCTION

Unmanned aerial systems (UAS) or vehicles (UAV) have seen significant proliferation over the past few decades. While primitive UAV systems can be traced back to the early years of aviation, the development of modern UAV systems arguably began with military programs of the early sixties and seventies. Military UAV development has since advanced considerably, with highly sophisticated UAV systems playing key roles in many conflicts. In recent years though, UAVs have been increasingly used for civilian applications. Some of the popular civilian UAV uses include mapping, surveying, cinematography, power line and other industrial inspections, environmental monitoring and precision agriculture.

The Chesapeake Bay is probably the most prominent geographic feature in the state of Maryland. With miles and miles of coastline serving residential, commercial, and industrial properties, and home to thousands of species of wildlife, the bay is a significant local and national resource. The bay is well known for its seafood, particularly crab and other shellfish, and the local shellfish industry is a multimillion dollar enterprise.

Environmentally, the bay is extremely sensitive. Serving as the watershed for portions of at least five different states, the bay is susceptible to all manner of pollution present in water runoff. Efforts to curb pollutants entering the bay have been underway for years, with a variety of programs targeting different pollution sources and their effects. One particular pollution concern is bacterial contamination from human, pet, and agricultural waste. Such contamination can infiltrate natural shellfish beds as well as human made shellfish aquacultures. Being that shellfish are regularly harvested and consumed by humans, such contamination is a significant health hazard as well as source of economic loss.

Efforts by state and local agencies have been underway for several years to control and mitigate the latter problem, as well as the many other concerns affecting the bay. As a common source of bacterial contamination is leaking sewage, positive identification of various sewage sources is critical. Leaking sewage can come from broken sewer pipes, failing residential septic systems, and illegal sewage outlets. In the case of failing residential septic systems and illicit outlets, the current method of identification involves lengthy door to door surveys, covering hundreds of miles of coastline. Completion of a single survey can take over a decade, and often yields only sketchy results – being dependent on the property owners' presence at the time of survey as well as their willingness to cooperate.

Considering the severe limitations of current survey methods, local officials are seeking new ways to both improve detection of pollution sources, as well as speed up the process and reduce cost. With recent developments in UAV technology, particularly the advent of relatively inexpensive UAV platforms and sensor options, a UAV remote detection of these pollution sources is a very promising idea. Developments in remote sensing techniques, particularly those aimed at vegetation monitoring and precision agriculture can be implemented to aid in identification of some of the pollution sources in question.

In this paper, we propose a tethered UAV system for the purposes of identifying specific sources of fecal coliform contamination harmful to the Chesapeake Bay shellfish. The paper is organized as follows: in Section 2 we explore several sources of fecal coliform and their characteristics. In Section 3 we discuss current remote sensing techniques that have potential in in this area. In section 4 we describe a general outline of a proposed UAV system. In Section 5 we discuss our general conclusions and our research plan going forward.

2. BACTERIAL POLLUTION SOURCES

Bacterial contamination of shellfish beds in the Chesapeake Bay is primarily due to fecal coliform bacteria from human and animals. Common sources include sewage leaking into the bay from residential or commercial properties, broken sewer pipes, illicit outlet pipes, agricultural runoff, and runoff from areas contaminated with pet and other animal waste. State officials typically seek identify these sources during the shoreline survey process. We shall focus on particular sources which have potential to be readily identified through remote sensing techniques.

2.1 Failing Septic Systems and Illicit Sewage Outlets

Residential onsite waste treatment systems are designed to effectively treat wastewater generated by households where public sewer systems are unavailable. A typical system consists of a septic tank, distribution chamber, drain field, and requisite piping. Wastewater sewage flows from the house plumbing system into the septic tank. In the septic tank, heavy solids settle to the bottom while grease and lighter particles float to the top forming a scum layer. Different strategies are used to ensure that solids are kept in the tank, while the semi-treated wastewater or effluent is allowed to exit. From the septic tank, effluent proceeds through a pipe until it reaches the distribution chamber. From the distribution chamber, wastewater flows out into a network of porous pipes embedded in gravel buried underground. These pipes form what is called the drain or seep field. The water seeps out of the pipes into the ground where dissolved wastes are absorbed into the soil and the water is effectively purified before ultimately rejoining the ground water [1].

Septic systems can fail in a variety of ways. Failures can occur in the tank, distribution chamber, drain field, or any of the associated pipes. Septic tanks can fail if they are overloaded with solids or receive a sewage influx that exceeds their capacity. Older tanks, particularly those made from metal, can corrode over time and ultimately fail. Distribution chamber and drain fields can fail as a result of system overload, clogs, pipe breakage, interference from tree roots, age, and other factors. Many of these failures result in sewage backups and or pooling water above and around the system.

A sometimes more damaging pollution source is when a resident or business simply positions an outlet pipe so that raw untreated sewage flows directly into the bay. Such practices are highly illegal, and can be sources of significant bacterial contamination.

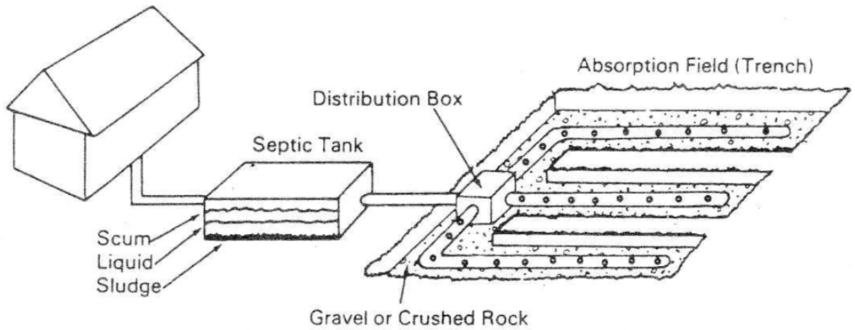

Figure 1. Standard septic system layout, as shown in [1].

3. REMOTE SENSING TECHNIQUES

3.1 Remote Sensing

Remote sensing is essentially the process of gaining information about a target through radiant energy [2]. A variety of techniques, both passive and active, exist across the electromagnetic spectrum. Oldest and most ubiquitous are sensors which operate in the visible spectrum. Also, infrared sensing is particularly useful and common, with a plethora of sensors designed to operate in the near infrared (NIR), mid wave infrared (MIR), and thermal or long-wave infrared (TIR a.k.a. LWIR), bands. Multispectral sensors allow simultaneous collection of spectral image data at multiple chosen spectral bands. Hyperspectral sensing involves collecting an essentially continuous collection of image spectra across a wavelength range to form a hyperspectral image cube. A vast plethora of techniques and methodologies are used in the design and operation of said sensors. The interested reader is advised to explore the subject from dedicated remote sensing texts.

Remote sensing for environmental monitoring has been a significant research subject for the past several decades. Many tools and platforms have been developed for a variety of different applications. A particular topic of interest has been remote vegetation and soil monitoring. Typical methods use visible, NIR, and thermal imagery to derive information about plant health, soil moisture content, plant water stress, and many other parameters. Several vegetation indices have been developed, including the Normalized Difference Vegetation Index (NDVI), Crop Water Stress Index (CWSI), Optimized Soil Adjusted Vegetation Index (OSAVI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), Photochemical Reflectance Index (PRI). Research has shown that these indices can be further correlated with other vegetation parameters [2].

Initial remote sensing systems for environmental monitoring were typically expensive and confined to satellite or dedicated airborne platforms. Such systems typically lack significant spatial resolution, and are limited by flyover times, scheduling requirements, etc. With the recent explosion in relatively inexpensive UAV systems, a plethora of research has been devoted to developing UAV remote sensing platforms for vegetation monitoring. The significant increase in spatial as well as temporal resolution afforded by such platforms has opened up entire new possibilities. In particular, agricultural applications show great promise. A UAV remote sensing systems can fly over a field or orchard, and within a few hours can produce a detailed map identifying areas of plant stress, vegetation decline, dehydration, etc. [3] [4] [5]. A farmer can then direct irrigation or pesticide application much more efficiently; this is popularly known as ‘precision agriculture’.

3.2 Remote Sensing of Failing Onsite Septic Systems

Often associated with septic system failure is a change in the vegetation in the vicinity of the failure. Leaking effluent can have a semi positive impact, increasing the nutrient and moisture content of the soil resulting in lusher vegetation. The opposite can also occur; too much water in the ground as well as the presence of effluent contaminants can result in vegetation stress and or death.

Sewage outlet pipes depending on their position on a property may exhibit similar signs to the failing septic systems. Pipes such that sewage flows over a portion of the property before entering the water may have vegetation changes as well as increased soil moisture content.

Given the characteristics of these failures, vegetation monitoring techniques are readily applicable to locate the associated vegetation and soil parameter differentials. Research as well as successful implementation of these types of techniques by local water management agencies appears in [6] [7] [8]. The aforementioned sources successfully implemented color infrared (CIR) imagery in the surveys. As a future prospect, [6] suggests implementation of such a system on a UAV platform. Both [6] [7] discuss using AVERIS hyperspectral data as well. The method employed by [8], expanded on prior efforts with CIR imagery by incorporating airborne thermal imaging as well. [8] also engaged in significant efforts to classify and characterize failure signatures, linking image data with other GIS information.

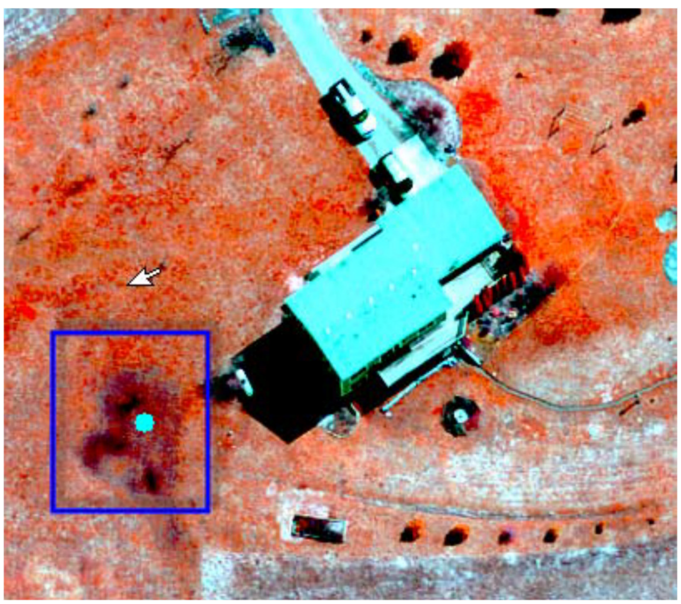

Figure 2. CIR imagery identification of septic system, as illustrated in [8].

4. PROJECT CONCEPT

The essential concept of this project is to build upon prior efforts in remote septic failure identification by introducing a specifically tailored UAV sensor platform. Thermal IR and multispectral imagery collected from a UAV platform has great potential to effectively identify the signs of failing septic systems, and in some cases illegal sewage outlets. Research has shown that CIR and thermal IR imagery are well suited to this task, given the nature of the failures and their influence on local vegetation. A significant amount of research has been performed on the implementation of multispectral, hyperspectral, and thermal imaging on UAV platforms [9] [10] [11] [12] [13] [14] [15], particularly in the area of vegetation monitoring. These methodologies are readily applicable to septic failure identification.

Collection of both thermal and multispectral image data will also allow the calculation of a variety of vegetation indices, which may be useful in further characterizing failure signatures. Data fusion and computer vision algorithms correlating failure signatures across different spectral bands is another avenue of potential research. A sample algorithm for target identification by correlating thermal and visual imagery from a UAV platform appears in [16].

For the initial phase of this project, we have identified a multi-rotor as our UAV system of choice. Multi-rotors are a popular choice for inexpensive remote sensing platforms. They allow great flexibility in sensor positioning as well as overall flightpath, and combined with the use of stabilized gimbal systems can yield very high quality image data. Off the shelf components and software are available to allow GPS navigation, automated flight planning, as well telemetry and wireless data transmission. Additionally, a multi-rotor is capable of vertical takeoff and landing, allowing the possibility of marine based operations.

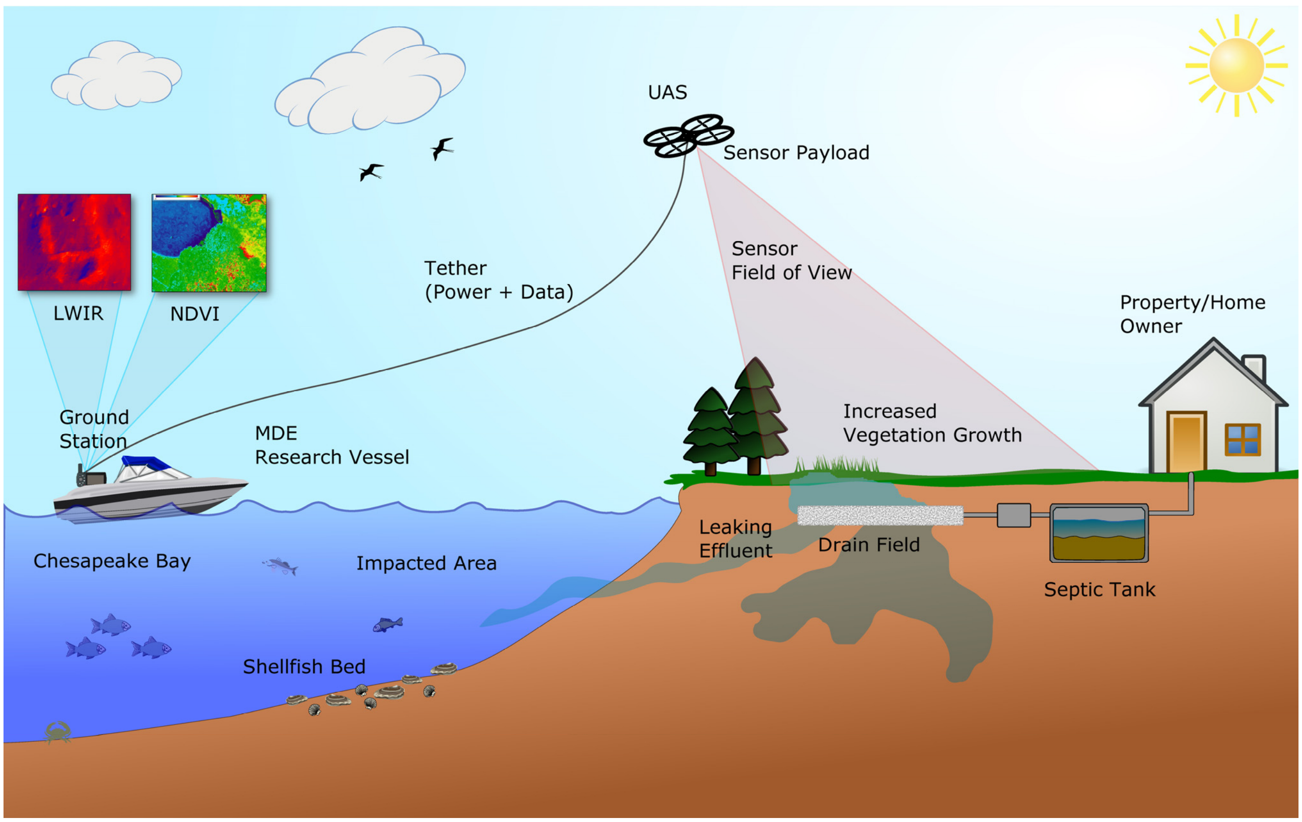

Figure 3. Proposed tethered-UAV system for failing septic system detection.

Our choice of sensors includes a multispectral camera with several visible and NIR bands, as well as an uncooled thermal infrared camera. Sensor selection will be guided by UAV operational requirements such as size, weight and power, as well as the quality resolution of image data output. Ideally, a thermal IR camera with full radiometric data will be sought. Many popular thermal cameras do not provide radiometric data, allowing only a qualitative assessment of thermal gradients within an image. Radiometric thermal image data will open the door to more precise analysis of obtained images as well as the option to compute vegetation indices requiring temperature data. Sensor selection will however be limited by budgetary constraints; as more sophisticated sensor options can easily approach the tens of thousands of dollars.

A common limitation of multi-rotor platforms is their flight time. Current battery technology typically only allows flight times in the range of 10 to 25 minutes, depending on payload weight. An additional albeit unrelated limitation is the current regulatory policy in the United States. Operation of small UAVs in US airspace for non-recreational use requires complicated and difficult to obtain FAA authorization. As such we have chosen to operate our UAV as a tethered platform. A basic tethered system receives power from a ground station, allowing for theoretically unlimited flight times. Additionally, tethered aerial systems are not subject to the same regulatory restrictions as normal aircraft.

Data obtained through our UAV sensor system will require a post processing phase to yield useful results. Images must be orthorectified and stitched together to form a large map of a targeted area. Relevant vegetation indices such as NDVI or CWSI can then be computed to form maps that will hopefully allow an analyst to spot the signatures of failing septic systems or illicit sewage outlets. Several off the shelf packages exist for this sort of data processing, primarily targeted for the precision agriculture and UAV mapping/surveying industries. Additional processing may be required for atmospheric correction of the data. Some research has shown that such correction is needed even for UAV imagery at relatively low altitudes [15].

With processed image data across multiple spectral bands along with computed vegetation indices, there exists possibility of developing algorithms for automated failure signature identification. Efforts in this area are part of fields such computer vision, and represent a possible future stage of this project.

5. CONCLUSIONS AND FUTURE WORK

We have presented our concept for an UAV-based remote sensing platform for identification of failing onsite sewage systems and illicit sewage outlets. These conditions represent significant sources of fecal coliform contamination to the Chesapeake Bay, strongly affecting shellfish beds and aquacultures and posing a significant public health hazard as well economic constraint. The vegetation change associated with septic failure make such failures ideal candidates for remote sensing identification via thermal and NIR imagery. Prior efforts in this area using traditional platforms have shown to be effective.

Success of this program could yield significant benefits to local environmental officials in their efforts to locate and curb pollution sources. Effective implementation of the system as part of a broad survey would likely lead to improvements in public health as well as increased economic opportunity. In the broader sense however, an UAV-based platform as described would not be limited to the Chesapeake Bay area. Watersheds across the country could benefit from such a program, as the problem of leaking sewage sources is ubiquitous to all areas where such sewage systems are found.

Our current goals include finalizing our sensor selection based on ultimate data collection goals, designing the UAV platform, selecting necessary system components and hardware, as well as researching and choosing post-processing software.

With a completed system ready, an initial data collection program will begin targeting known failure sites. Data obtained will be used to form a baseline for characterizing failure signatures. To appropriately plan this initial survey, further research is needed to understand the effects of atmospheric conditions on spectral reflectance data. Also important is the role daily and seasonal environmental cycles play in influencing the vegetation changes in question.

A future phase of this project would to be to explore additional remote sensing techniques that could increase the scope of the pollution sources detectable – beyond failing septic systems. A sophisticated UAV system capable of detecting a wide variety of pollution sources and contaminates entering the Chesapeake Bay would be a highly valuable tool. Such a system could no doubt play a significant role in efforts to clean up the bay as well as protect it for years to come.

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