A Holistic Approach to Emergency Communications Systems and Rapid Response

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ABSTRACT

PROJECT CANVAS:
A HOLISTIC APPROACH TO EMERGENCY COMMUNICATIONS SYSTEMS AND RAPID RESPONSE

by Thomas Shu

This paper describes the need to build a scalable communication system for rapid deployment in emergency scenarios. Utilizing low altitude platforms, a support intranet can be raised above a disaster scene utilizing different layers of radio technologies and protocols, such as WLAN and FDMA, taking advantage of ISM Band and L-Band networks. The main purpose of this system is to provide a means of communication to local aid workers, assist in land surveys and provide real time images, as well as assist in cataloging missing persons.

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LIST OF SYMBOLS

Symbols	Definition	Units (SI)
a	Acceleration	ft/s^2 (m/s^2)
d	Distance	inches (cm)
f	Focal Length	inches (cm)
g	Gravity	ft/s^2 (m/s^2)
h	Size of Object	pixels
i	Height	pixels
m	Mass	lbm (kg)
n	Number of Sides	
v	Velocity	ft/s (m/s)
w	Width	pixels
C_d	Coefficient of Drag	
D	Diameter	inches (m)
F	Force	lbf (N)
S	Surface Area	in^2 (m^2)
Greek Symbols	**Definition**	**Units (SI)**
φ	Angular Coverage	Deg or Rad
θ	Viewing Angle	Deg or Rad
ρ	Density	lbs/in^3 (kg/m^3)
Subscripts	**Definition**	
()i or ()0	Initial	-------------------
()f	Final	-------------------
Acronyms	**Definition**	
API	Application Programming Interfaces	-------------------
AWB	Automatic White Balancing	-------------------
BACN	Battlefield Airborne Communications Network	-------------------
CDGPS	Common Differential Global Positioning System	-------------------
CotS	Commercial off-the-Shelf	-------------------
CV	Computer Vision	-------------------
ENS	Emergency Notifications System	-------------------
FEMA	Federal Emergency Management Association	-------------------
FPS	Frames-per-Second	-------------------
HOG	Histogram of Oriented Gradients	-------------------
HSV	Hue, Saturation, Value	-------------------
IMU	Inertial measurement Unit	-------------------
IRHC	Interim Haiti Recovery Commission	-------------------
ISM	Industrial, Scientific, and Medical	-------------------
ISR	Intelligence, Surveillance, and Reconnaisence	-------------------

ISS	International Space Station	-------------------
LAP	Low Altitude Platform	-------------------
LIDAR	Light Detection and Ranging	-------------------
LMR	System Land Mobile Radio	-------------------
LTE	Long Term Evolution	-------------------
LTE-U	LTE Unlicensed	-------------------
M2M	Machine-to-Machine	-------------------
MINUSTAH	United Nations Stabilization Mission in Haiti	-------------------
NGO	Non-Government Organization	-------------------
NOAA	National Oceanic and Atmospheric Administration	-------------------
NYCWiN	New York City Wireless Network	-------------------
P2P	Point-to-Point	-------------------
PWM	Pulse Width Modulation	-------------------
RADAR	Radio Detection and Ranging	-------------------
RAM	Random Access Memory	-------------------
SBD	Small Burst Data	-------------------
TSAT	Transformational Satellite	-------------------
UAS	Unmanned Aerial System	-------------------
VoIP	Voice over Internet Protocol	-------------------
WANET / MANET	Wireless Ad-Hoc Network	-------------------
WEA	Wireless Emergency Alerts	-------------------

CHAPTER 1

INTRODUCTION

Communications systems are key in giving access and providing news worldwide. As a leading technology, communications systems have propagated in a variety of ways, revolutionizing mail, electromagnetic technologies, and wireless systems. Early designs relied on analog systems and were unreliable leading to delays due to distance and high operator workload. Modern day systems are far more reliable, in part because of Moore's Law, as well as the upsurge in the maker movement leading to consumer creators. The result is cheaper, more robust technology that can be leveraged in high-risk situations. This makes it ideal to step into a sector that typically is restricted, as well as to re-evaluate technologies associated with critical scenarios, such as emergency communications systems.

Emergency communications systems is such a system that traditionally has required a large amount of funding for situations that may not arise for years. This could result in negligence of the system or improper training. Current emergency communications systems rely on both civilian systems (i.e. cell towers and mass notifications systems), as well as ad-hoc networks. However, while there are classifications for such systems, the systems themselves are dependent on the deployed area creating fragmentation.

In this paper, the aim is to develop an emergency communications system that is scalable to different scenarios. To do this, the paper will focus on emergency and disaster classifications, explore different communication systems currently in use, and attempt to develop a systems design for a new system (Project Canvas), including operations. Regional requirements will be taking into account, but the focus will be on the ability to be unobtrusive, affordability, and reducing reliance on outside resources for the system to operate.

1.1.0 Background

Disasters are not defined by magnitude, but by effect on the surrounding environment. As an illustration, the city of San Francisco is well equipped for a variety of disasters thanks in part to the San Francisco Department of Emergency Management, which publishes reports and action plans for the citizens. These reports cover everything from civil unrest and dam failure to urban conflagration and terrorism, along with warning systems located throughout the city. [1] While San Francisco has experienced multiple earthquakes in the last decade, the city has been steadily improving infrastructure and city planning to limit damage. However, Louisiana has experienced many situations where the Federal Emergency Management Agency (FEMA) has had to report major disaster declarations in the recent years. [2] Therefore, one can define a disaster based on key features, including how the disaster resonated across a group of people, how that impact stands the test of time, and the social and economic impacts felt by the event.

1.1.1 Disaster Research

It is prudent to look at recent disasters to figure out what has gone well and what has failed. Three incidents stand out: Hurricane Katrina, Hurricane Sandy, and the Haiti Earthquake of 2010. Hurricane Katrina represents one of the largest natural disasters to ever hit the United States. Hurricane Sandy represents an unprecedented situation where preparation was scarce. The 2010 Haiti Earthquake represents a need for better planning and discussion between nations.

1.1.1.1 Hurricane Katrina

Hurricane Katrina represents a major disaster for the gulf coast for several reasons. The hurricane originated in the Gulf of Mexico, swathing over Southern Florida initially as a Category 1 hurricane at 70 knots (kt). After gaining speed again in the Gulf of Mexico, it reached

Category 5 status at 150 kt and extending 90 nautical miles. Moving north, the hurricane reduced in intensity and upon reaching landfall, it had decreased to a Category 3 (estimated speed was 105 kt) at the Louisiana-Mississippi border. From there the hurricane continued over the southern and central Mississippi, decreasing to a Category 1 and, eventually decreases and dissipates near the Great Lakes. [3]

The result of this disaster was the costliest tropical cyclone to hit the mainland United States in recent history. Taken from the National Oceanic and Atmospheric Administration's (NOAA) report on the costliest and deadliest hurricanes, the report estimates the total number of casualties to be approximately 1,833 based on data from 5 states. [4] The total damage cost is approximately $108 billion. According to the reports, the hurricane was outside the scope of design for much of the infrastructure built in the area. [5] This caused communication tower failure, flooding, and a shutdown of many services. In the case of Louisiana and Mississippi, a dam failure escalated the situation, causing flood levels to rise above 8 feet in some areas. [3] These situations were critical in the overall escalation of the damage. Many of the communication towers, including cellular service towers, internet services, and 911 services still became inoperable. [5] The remaining towers were expected to handle the influx of calls from various law enforcement organizations, concerned families and friends, and those attempting to provide aid. [6] [7] This was coupled with various planning issues, most notably, generators placed on the ground floors. Various companies were unable to access key generators due to placement on the ground floors, preventing personnel from accessing the generators due to the flooding and risk of shock. [8] In addition, federal relief workers' satellite phone services were inoperable, leaving the only a few AM radio stations and amateur radio services available for rescue services. This caused delays because communications could only flow through a single node. [9] Local infrastructure, planning, and communication systems failed when relief personnel needed it the most.

1.1.1.2 Hurricane Sandy

Residents of the northeastern United States, Canada, and the Caribbean experienced similar distress when Hurricane Sandy struck. Hurricane Sandy is touted as the largest Atlantic hurricane and the 2nd most expensive hurricane ever recorded. [10] It was responsible for at least 147 deaths [11] and exceeded $50 billion in damages due to its unprecedented pathing. [12] Flooding exceeding 8 feet above ground level, power outages exacerbated by wind, surge, and blizzards made this storm a nightmare to deal with. [13] [14] While this storm was both predicted and telegraphed to the public, the lack of precedent made the hurricane difficult to deal with. After the hurricane had hit, it was discovered that 25% of telecommunications, broadcast, and cable networks were brought down during infrastructure collapse (50% in some counties). [15] [16] Many of these counties relied on cellular or radio communications to both inform the public as well as to coordinate rescue efforts. With those systems down, dissemination and control of information became non-existent leading to greater confusion and fear.

1.1.1.3 The 2010 Haitian Earthquake

From 2001 to 2011, disasters caused 780,000 deaths with earthquakes accounting for 60% of that. [17] Haiti represents a major portion of that, causing approximately 160,000 deaths in the capital city of Port au Prince alone. [18] The earthquake's epicenter was near the town of Leogane, approximately 16 miles west of Port au Prince and caused massive damage to the surrounding area. It was classified as a magnitude 7.0 earthquake with approximately 52 4.5 magnitude aftershocks over the course of a few days. 73% of the buildings in the affected areas were one story buildings made of sheet metal, concrete, and stone. Schools, government institutions, and general infrastructure was designed much in the same way. [19] Many of these facilities, as well as, communications systems, air, land, and sea transportation facilities were not designed to handle earthquakes and the damage from this earthquake has had lasting impact. The world responded with a great fervor, creating the United Nations Stabilization Mission in Haiti (MINUSTAH) and the Interim Haiti Recovery Commission (IHRC). [20] [21] [22] However, rescue and disaster relief efforts were hampered due to international organizations and coordination efforts failing.

1.1.2 Common Elements

These disasters share common themes where network infrastructure checks, communications, and disaster response could have mitigated some of the effects. Communications was paramount, where damage to various critical elements led to further failings down the line. While there can be classifications based on wind speed, quake levels, etc. location and preparedness will make all the difference. Hurricane Sandy, Hurricane Katrina, and the Haitian Earthquake caught officials and rescue staff unprepared. The extent of the damage was unpredicted at the time and it is only with hindsight that one can judge the events and the actions.

1.2.0 Current Approach to Disaster and Disaster Prevention

There are several different documents citing the propagation of emergency communications systems in the world, utilizing a variety of different platforms and systems. These platforms can be broken down into civil systems and non-government organizations (NGOs). Civil systems could include military intervention, satellite imaging of the surrounding area, and peacekeeping forces, while NGO include organizations such as the Red Cross, Engineers and Doctors Without Borders, or The Wikimedia Foundation. The intent of a NGO is to advocate for human rights, health, environmental, and developmental work in certain areas. Disaster management flow [23] is broken down into 4 main structures:

- Pre-Disaster Mitigation/Prevention: The development of infrastructure standards and tools to extend the length of human life. These things include assessing the risk of certain areas and developing objectives to mitigate those risks.
- Pre-Disaster Preparedness: For when a crisis strikes, the public knows what to expect and how to deal with the damage. This includes training and drills, public warning tests, and information fliers.
- Disaster Response: When and just after the disaster has occurred, two things must happen in quick succession. First comes the assessment of damage and assisting the public where possible. Second is minimizing damage from secondary and repeated impact. This can include setting up shelters, emergency distribution of food, and search and rescue.
- Post-Disaster Recovery: Post-disaster recovery falls into two categories, short term and long term. Short term tasks include setting up temporary housing or key infrastructure restoration, while long term tasks include the clearing of debris and detailed damage assessment.

These 4 structures are based on the necessity for key services, including the need for communications between first responders, emergency medical and infrastructure facilities, surveillance, weather, etc.

Communication relies on preparedness at all levels. A few questions to ask when looking to design a new one include: [23]

- What systems are currently available and how can the systems be made resilient to natural wear and tear?

- How do we train both local public safety officers as well as international ones on the operation and configuration of the equipment?
- When the disaster occurs how can systems be restored and what dangers does that systems pose?
- How can we improve for next time?

Those are questions that are posed for every step of the disaster cycle and one that is constantly being reviewed as technology advances.

During a crisis, 3 scenarios arise for communications: No damage, partial damage, and complete failure. [24] No damage is ideal since it tells disaster managers that systems were well prepared. In such a case, standard operating procedures can be followed and the communications platforms are fully operational. In a partial damage scenario, some of the base stations may be inoperable leaving a dead zone in network coverage or causing the other structure to pick up the slack. In that situation, there may be temporary structures available that can relay the information otherwise the network may be overwhelmed. In a severe disaster, a complete failure may occur, which prevents authorities from operating. In such a case, contingency measures such as short wave (high frequency) radios or reliance on satellites (i.e. INMARSAT, IRIDIUM). Both systems have flaws – HF radios have limited range and require point-to-point connections, while satellite coverage depends on region, with few voice lines and limited broadband connection available during a true emergency. The use of amateur radio is also available and is often utilized. Examples of its use include the 9/11 attacks, Katrina, and Sandy (where increased operators were called in specifically to mitigate disaster effects). [25]

1.3.0 Resulting Improvements

Technologies are rapidly being utilized in disaster scenarios. Being interconnected through cell phones and smart phones, many agencies are stepping up to modernize aging systems. FEMA, which took heavy criticism for its handling of Katrina, upgraded its support network and is taking advantage of Twitter to broadcast event news and relief situations. [26] Wireless Emergency Alerts (WEA), notifications sent directly to a phone, have also been developed within the last few years to better facilitate notifications to the public. [27] While these technologies are designed to push information to the public, ad-hoc communications platforms for relief personnel are beginning to take form, such as Northrop Grumman's development of New York City Wireless Network (NYCWiN) due to the events of September 11, 2001. [28]

1.4.0 Communications and Surveillance Systems

An emergency communications system needs to be designed with ease-of-use in mind. Its purpose is to disseminate information to key distributors and staff, while informing the public. Due to the nature of the design, an emergency communications system must be flexible, intuitive, and quick to set up. [7] Ideally, these systems would be highly interconnected and would work with existing infrastructure, as well as, future technologies that may become available. Inadequate emergency systems can easily disrupt the best of intentions and, at worst, cost lives. However, due to the inundation of information from cell phones, media, and general sensationalism of disaster coverage, accurate information can be hard to come by and it is difficult to assess credible sources. However, there are some tried and true technologies which have permeated the defense and disaster markets.

There are several different systems available on the market. These systems can be as complicated as ground line phone networks and Voice over Internet Protocols (VoIP) to simple loudspeakers. Communications and surveillance systems go hand in hand since plans need to be developed with as much information as possible. Table 1.1 and Table 1.2 describe common communications and surveillance systems, including use cases. Also, combined in the tables are advantages and disadvantages of the systems. This is by no means a complete list, but that is part of the problem. With so many options and systems, operators training to become ground personnel are often overwhelmed by the sheer number of options.

Table 1.1: Examples of Communications Systems Used in Emergencies

System	Description/Example	Advantage	Disadvantage
System Land Mobile Radio (LMR)[1] [29]	Computer controlled two-way radio for team meetings (TETRA Trunked Radio Systems, Walkie-Talkie, etc.)	Automatic “talk group” assignment	Bulky Slow
		Fewer Discreet Channels Required	May not be usable
			Lack of flexibility
			Limited Uses
Emergency Notification System (ENS) [30]	Automated service used to notify many people (Alarms, Text Notifications, etc.)	Simple and quick to manage	Misses certain groups
		Easily accessible communication for citizens	Reliant on access
Satellite Utilities	Phones that connect to positioned satellites (INMARSAT, Globalstar, etc.)	Able to connect even in remote locations	Requires subscription plan
		Versatile system with various plans	Limited services depending on network
			Low data rate
			Unable to create groups
Urban Mobilization	Ground personnel trained to inform and direct.	Simple and Reliable	Limited
			Slow
			Dangerous

[1] A land mobile radio system is a portable 2 way radio. In the case of Haiti, the system was a Motorola system with Smartzone 3.0. Some of these systems are large and heavy, sitting in an automobile to be transported, which means that if there are building collapses, it may be difficult to move the system where it need to be.

Table 1.2: Common Surveillance Systems Used in Disaster Zones			
System	**Description/Example**	**Advantage**	**Disadvantage**
Unmanned Aerial Vehicles	Used to fly over areas with damaged infrastructure	Real Time Situational Awareness	Requires many hours of training
		GPS/INS Navigation	Unable to fly in certain weather conditions
		~3 Mile Radius from Ground Station	Requires notifying appropriate agencies and airports
	Service that allows and carries visualizations of a terrain	Previous Analysis done on location and terrain	Requires updated surveys and databases
		Easily accessible with many databases supporting locations	Reliant on outside communications and databases
Satellite Imagery	Satellites that sit in LEO or GEO Orbits	1 meter resolution	Most databases are not public access
		Updated every 30 minutes to 3 days	Site of interest may be covered due to weather or debris

Features that are considered when creating any communications system include time, ease-of-use, and accuracy of information. A disaster zone is a place where every second counts. An operator cannot spend time verifying the accuracy of information or figuring out how to use the system.

1.5.0 Aerodynamic Bodies

While surveillance and communications exist for terrestrial bodies, there are advantages to developing an airborne system. An aerial system can provide real time weather and surveillance system when outfitted with weather, vision-based, and system health sensors. This provides greater line of sight and an ability to survey a larger area. The higher elevation also clears obstructions making it easier for terrestrial equipment to connect with it. The higher look-angle also allows for greater coverage, meaning that fewer base stations are required when compared to similar terrestrial based systems.

This project has several technical challenges in terms of aerodynamics. The vehicle must have a level of hovering proficiency, be able to hold its position and orientation for long periods of time. The vehicle must be able to do this despite weather variance and with minimal takeoff distance. It must be able to operate mostly autonomously, while still looking for operator input. It needs to be able to support the power system, system health modules, various communications payloads, and processing units that are aboard the vehicle. Given its airborne nature, the system must remain relatively light weight and fit within size constraints to reduce impact on other mission critical equipment.

This system must be able to manage a variety of situations including, the possibility of high turbulence scenarios. As such, there are additional restrictions, including low pitching moment coefficient, high lift capabilities, and the ability to self-stabilize. During these cases, hysteresis associated with the pitching moment, as well as stall are constant concerns. This affects both the flight of the craft itself and its various failure scenarios. The two types of systems available are passive systems and active systems. In terms of active systems, rotorcrafts, airships, and aircrafts are systems that are both stable and reliable. As for passive systems, options increase, where products can range from simple spherical aerostats to helikites. Table 1.3 shows some of the advantages and disadvantages of some systems available.

Table 1.3: Common Aircraft Systems for Emergency Situations		
System	**Advantage**	**Disadvantage**
Quadcopter	Can be extremely light weight	Not usable in all-weather scenarios
	Altitude and placement can easily be adjusted	Steep learning curve with a high chance of error
	Can be deployed quickly and easily	Payload size and operations time is dependent on weight and battery size
	Is widely available on the market	Requires constant supervision
Aircraft	Capable of flying multiple days	Cost can be incredibly high
	Altitude and placement can easily be adjusted	Requires many hours of training with a high turnover rate
	Can be deployed quickly and easily	Movement can develop connectivity problems with wireless equipment
Airship	Capable of staying in a single location for long periods of time	Requires extensive ground facilities and operating groups
	Able to hold a variety of payloads	Heavily affected by weather at a small size
		Requires a thick, heavy skin to handle internal pressures
Balloon	Simple and easy to distribute	Heavily affected by weather
	Can be deployed quickly and easily	Lack of control surfaces makes orientation difficult
	Very little damage in case of failure	Lack of clear mounting points
Net Curtain Balloon	Stabilizes better to changing pressures	Heavily affected by weather
	Simple and easy to distribute	Unstable with few self-righting capabilities
	Disposable and cheap	Net does not do much more than stop the balloon from rotating
Helikite	Relatively gas tight	More difficult to reposition than an active system
	Utilizes both wind and helium lift to rise to high altitudes	
	Easy to deploy and easy to maintain in the air for long periods of time	

1.5.1 Safety Systems

While this system will be designed to be as robust as possible, there will always be a chance for failure. To assure that the aerial portion of the system does not ever free fall, a safety system needs to be added. For safety systems, parachutes and auto rotators are tried and true systems for both helicopters and rocket enthusiasts. The purpose of the safety system is not only to protect the system from taking extreme damage, but for the safety of those that may be around. For that reason, reducing the complexity of the system would be in the project's best interest, where redundant options may also be included. The greatest concerns for this type of system is its reliability, weight, and complexity. Table 1.4 discusses some of the advantages and disadvantages of the systems.

Table 1.4: Common Safety Systems for Aerial Crafts

System	Advantage	Disadvantage
Parachute	Passive system with no moving parts	No descent control
	Light weight	Unreliable in high turbulence weather scenarios
	Cost effective	Lots of testing to assure stowage and unfurl patterns
	Does not require external power	May cause aerial structure to become entangled
Autorotator	System used in helicopters and other high stress scenarios	Highly sensitive to weather
	Passive system with good descent control	Tall, dense vegetation may decrease viability
Active Propeller System	Greatest control of descent	Requires separate power source
		Unreliable in high turbulence weather scenarios
Inflatable Drop	Requires no control system	May cause damage to surroundings
	Unaffected by weather	

CHAPTER 2

PROJECT APPROACH

2.1.0 Project Objective

Modern communication systems are complex, not only due to the system infrastructure, but also because of the universality of the system. Although designs exist for low-altitude platforms, research is sparse and exploration is just beginning. Reasonable feedback still needs to be acquired. As such, projects need to act on several different fronts to be successful. These fronts can be categorized as reliability, ease-of-use, universal, and range. The purpose of this project is to create a rapidly deployable disaster communications system capable of disseminating critical information to key distributors and emergency staff.

2.2.0 System Phases

There are 3 phases for Project Canvas. Phase I is developing the systems level design – defining key elements of the project in a comprehensive report. Phase II is analysis and component testing – this includes the use of entry level analysis using solvers and simulations for ideal conditions, expected conditions, and failure modes. Phase III is defined to be a full suite of integration and testing – this includes physical mockups and undergoing environmental testing. The completion of this paper will define the end of Phase I design.

2.3.0 Proof of Concept Design Approach

The purpose of Project Canvas is to create a unified system; a system that is versatile and recognizable. At its base, the idea is to utilize low altitude platform (LAP) to generate an Ad-Hoc network and surveillance platform. The network would serve as a means of communications and as a file repository allowing responders to communicate across agencies. A surveillance network works to provide security during recovery and cleanup processes. This gives ground personnel an extra source of information to observe an area for signs of life, debris, and to determine if special precautions are needed before moving in.

In addition to the local network, this system can assist in reliving pressure on critical lines, such as cellular frequencies. It is often said that, disaster hits families the hardest. A natural response for a worried family member is to attempt to reach loved ones. Unfortunately, this action may cause cell towers ill equipped to handle that many signals to lock up. In Hurricane Katrina, the Louisiana State Police Radio Network, Satellite Radio Phone Network, Cellular towers, and 911 call centers all went down due to the high traffic which lead to congestion and eventual failure. [1] This system is designed with the intent of supplementing and assisting those networks with the option of operating without any other networks.

As such, this system has 3 components: terrestrial base stations to interpret and provide a log of information, an aerial system enabling cross compatibility of various technologies and provides a better line of sight to users, and small burst data (SBD) systems to send and receive data from international terminals.

CHAPTER 3

DESIGN APPROACH

3.1.0 Mechanical System Design and Research

As mentioned, a LAP is an ideal platform – allowing for greater coverage for the communication equipment and allowing for greater line of sight for surveillance systems. The design considerations that this needs to meet are that the hardware must be compact when in its stowed configuration, the design is not susceptible to movement by high winds and is stable, it can be carried by a single person, and it is easy to set up and stow. Given these considerations there are many different configurations that would fit the criteria, including copter style UAVs, as well as lighter than air vehicles like airships and balloons.

A. *Copter Style UAV* [31]
Copters have gained popularity recently due the rise of "action" sport cameras. While it would be possible to design for a helicopter configuration, a quadcopter simplifies the design and control to four motors, controlled by pulse width modulation (PWM), and can be stowed easily into a compact space. However, these vehicles require quite a bit of power to operate, which means that range is limited by the battery (a DJ Phantom 4 has a rated flight time of 28 minutes). While the price of a quadcopter has dropped significantly due to popularity, many are still extremely expensive and require a robust control system to keep the device airborne in less than ideal weather. There is also a higher cost associated with buying/renting the quadcopter itself and paying for an experienced pilot.

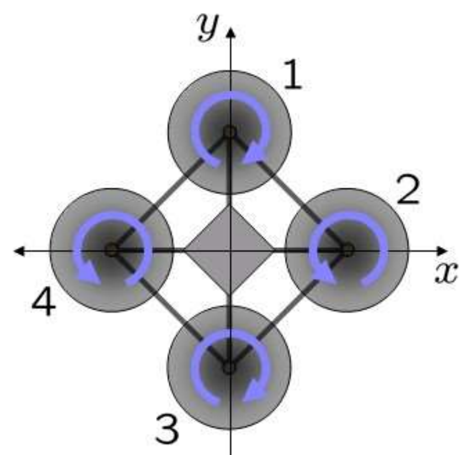

Figure 3.1: Schematic of Reaction Torques on Each Motor of Quadrotor Aircraft [31]

B. *Inflatable Device* [31]
Inflatable devices, also known as lighter-than-air vehicles, are another solution. The system relies on passive lift capabilities and do not require a complex control system for flight. Consumables such as helium and the issue of powering the avionics might be a challenge, but portable inert gas canisters and compressible gas systems are available on

the market today. (Helium tanks are readily available due its use by military personnel.) However, there is a limit to the weight that such systems can handle limiting the flexibility and usability of such a system. The systems mentioned in Table 1.3 only scratch the surface of available systems.

C. *Aircrafts* [32]
Northrop Grumman's Global Hawk, Aurora Flight Sciences' Orion Unmanned Aerial System (UAS), and the Global Observer, are just a few UAVs that are available for research and military use. The Orion UAS is a specially designed craft for Intelligence, Surveillance, and Reconnaissance (ISR), in addition to communication relay missions. It is capable of high altitude flight (30,000 ft) for 120 hours and a 1000lb payload. While these specifications are high, there are key concerns with this project. While these crafts come in a variety of sizes, many typically sit higher in weight and size than any of the other vehicles. There is also a matter that these crafts typically run off jet fuel, which is a limited resource when disaster strikes. Cost is comparable the copter style UAVs, where a trained pilot is also needed to watch and control these crafts. These crafts may one day be viable, with new crafts being run off solar energy. The Ascenta-Hale is one such craft, capable of flying for 3 months carrying a payload of 25 kg.

The criteria for the aerial lift system is defined as follows:

- *Payload Lift Capabilities*
  The craft's ability to lift mass per volume.

- *Durability*
  The ability for the craft to handle buffeting in high wind scenarios and its ability to maintain its structure. This also includes how the craft handles undesirable weather (i.e. rain, snow, etc.) and the likelihood that the craft may become inoperable.

- *Ease of Handling*
  The ability to assemble and deploy the craft with minimal training and with a single person.

- *Fuel Requirements*
  The craft's ability to maintain altitude for a given duration without additional fuel or consumables.

As mentioned in Chapter 2, safety systems are also a key concern. The key design considerations for this system are reliability and ease of stowage. Safety systems are items of last resort, and may not be regularly tested. Therefore, to reduce the chances for failure, the system needs to be as simple as possible and require few moving parts. Ideally, there will be no expendable resource. Given these considerations, heavily tested systems such as auto-rotators, parachutes, and inflatable landing devices would be better suited, however the case can be made for active propelling systems to best control descent and landing.

The criteria for the safety system are as follows:

- *Reliability*
  The ability for the system to function despite not having been tested or maintained over long periods of time.

- *Weight*
  The mass of the system and its stowage system.

- *Complexity*
  The number of moving parts a system has and the mechanism to stow the system.

- *Durability*
  The ability for the system to handle buffeting in high turbulence and how the system fairs in undesirable weather (i.e. rain, snow, etc.).

3.2.0 Communications System Design and Research

The proliferation of various communications standards has been rapidly advancing with the advent of mobile device development. The result of this is that new technologies and standards come out every year. While this is good in terms of an advancement standpoint, advancing technologies create an issue of cross compatibility and future-proofing designs. There are quite a few different technologies that would be suitable. The technologies specific to this project must be able to handle data voice point-to-point (P2P) communications, machine-to-machine (M2M) communications, as well as the handling of data.

A. *Industrial, Scientific, and Medical (ISM) Band Technologies*
   ISM band includes 2.4GHz and some 5GHz radio frequencies. These technologies include Bluetooth, 802.11 standards of WiFi, and military radios. ISM bands are unlicensed, meaning that anyone can set up a network system so long as the hardware is approved by the government. This makes the technology easily accessible to students and researchers.

B. *Long-Term Evolution (LTE) Networks* [33]
   LTE is a high-speed standard for wireless access. Traditionally reliant on fixed infrastructure to develop connections, new standards may become available to use LTE on unlicensed bands (LTE-U). In addition to this, Release 12 of Third Generation

Partnership Project (3GPP) makes it so that P2P features make it so that LTE networks are no longer reliant on radio access networks and user equipment. However, the system is heavy and every node must be active for the system to work properly.

C. *Satellite Communications*
Various communication satellites are available for those willing to utilize satellite communications. Amateur (ham) radio satellites is touted as the go-to system when communications black out and have been used in the September 11 Attacks and during Hurricane Katrina. Iridium and Globalstar's satellite network are also available for low data solutions.

3.3.0 Surveillance System and Mapping

Surveillance and mapping goes hand in hand with communications, relying on the same data lines. Surveillance systems and mapping systems will give personnel on the ground the ability to survey the area before moving into high impact areas. Since the system is mounted on the LAP, weight, accuracy, size, power, and range requirements are key considerations among others.

A. *Light Detection and Ranging (LIDAR)* [34] [35]
LIDAR utilizes lasers to generate a 3D map of a given area. Utilized by the National Oceanic and Atmospheric Administration, as well as Google's self-driving car (Waymo), it can be used to generate accurate images of the sea floor or various pedestrians while a vehicle drives by. However, the detection ability is severely hampered by rain and snow type weather and may cause disruption without additional work.

B. *Radio Detection and Ranging (RADAR)*
Radar works by sending out a pulse of electromagnetic waves and looking for reflections off objects and surfaces. The issue with radar is that there may be multiple sources of interference including scattering of signal or cluttering due to weather or atmospheric effects. Radar also typically requires large complex equipment including antennas, transmitters, duplexers, and receivers, which increase the weight of the craft.

C. *Vision Based Sensor*
Vision based sensors are cheap and efficient, with the only requirements being a camera and someone to review the images. The difficulty lies with the amount of data that the images captured takes up and the necessity for an individual to review it or complex data reduction techniques to flag images of potential interest.

D. *Common Differential Global Positional System (CDGPS)* [36]
While a GPS system is necessary to relay positions of relief workers, GPS can also be used to determine terrain and conditions. This method is utilized by Google to receive traffic data for its "Google Maps" system. Taking it a step further, by utilizing the GPS

on aid workers and comparing it with previous data of that area, one can accurately determine obstructions or how the terrain has changed.

E. *Infrared*
Infrared sensors work by detecting infrared radiation left on a body. These sensors are commonly found in night vision devices, missile tracking devices, water analysis, among other things. The technology is extremely versatile, but since all objects can emit infrared radiation, it is subject to a lot of noise.

3.4.0 Microcontroller Considerations

This piece will sit aboard the flight platform, meaning that power, weight, and volume are major concerns when selecting parts. These pieces will be used to control the flight deck which includes the ISM band radio and transmitter, the surveillance camera, and the flight equipment. The processor needs to be able to handle running all those pieces of equipment at once.

A. *Teensy 3.2 (Arduino)* [37]
Arduino is popular in the maker community for being easy to use and easy to learn. The Teensy is a small, high powered device using the Cortex M4 chipset with a rated speed of 72 MHz and 64 Kbytes of random access memory (RAM) on a 32-bit processor. It has an output voltage of 3.3 volts across the I/O pins and an input voltage up to 5 volts. While the Teensy can use both Arduino's IDE and C++ natively, it suffers from low processing power compared to the other controllers on this list.

B. *Beaglebone Black / X15* [38]
The BeagleBone Black and the BeagleBone X15 run on an ARM Cortex-A8 (1GHz) and a dual-core Cortex-A15 (2x1.5 GHz) respectively. The BeagleBone Black has 512 Mbytes of DDR3 RAM with an input voltage of 5 volts and an output of 3.3 volts on a 32-bit processor. The X15 is far more powerful than the Black, hosting 2GB of RAM and more I/O with a dedicated GPU.

The slew of I/O on these boards makes it great for prototyping, but only adds weight if the pins are left unused. Also, the BeagleBone Black lacks a dedicated graphics processing unit, instead relying on` software. The X15 has a dedicated GPU, but also doubles the size of the Black and increases the weight with more I/O.

C. *Raspberry Pi 3 Model B* [38]
The Raspberry Pi is an extremely popular prototyping tool with lots of support over the web. It has a 1.2 GHz 64 bit quad-core ARMv8 with built in wireless functionality. It supports a VideoCore IV 3D graphics core, with 1 GB of RAM. The specifications are close to the Pine64+, but has a stronger user base and appropriate modules if added

functionality is needed. It is also compatible natively with the Raspberry Pi Camera, which will be discussed in Section 4.1.3.2 A.

D. Pine A64+ 2GB [39] [38]

The Pine A64+ is a newly released device from Kickstarter which comes in to be direct competition against the BeagleBone Black and the Raspberry Pi. It features a 64-bit Quad Core ARM A53 clocked at 1.2 GHz with 2 GB of RAM and a dual core Mali 400-MP2 GPU. While it does not match the ODROID-C2 in terms of specifications, it makes up for this with a dedicated camera port built in.

E. ODROID-C2 [40]

The ODROID-C2 is the most powerful of the currently available microcontrollers on this list. It is designed for Debian (Ubuntu 16.04) and Android (5.1 Lollipop) systems and its specifications reflect that. It features an Amlogic ARM Cortex-A53 quad core clocked at 2GHz with three Mali-450 GPUs and 2GBs of RAM. In addition to these things, it has an onboard IR receiver. However, it does not have a real-time clock, which is something that the Arduino and Pine A64+ featured, but it can be added on through the built in GPIO pins.

F. Hybrid System

The final option is a hybrid system, where two microcontrollers will be working in tandem, but focused on different tasks. Many of the tasks aboard the flight unit are mundane with video processing and port forwarding taking up a majority of the processing power. These two high power tasks can be split making combinations like a Teensy to handle menial tasks and a Linux based device to handle the video.

Table 3.1: Avionics Trade Study						
	Beaglebone Black	Raspberry Pi 3 Model B	Teensy 3.2 (Arduino)	Pine A64+	ODROID-C2	Importance
Cost	~$45	~$35	~$20	~$30	~$40	Low
Chipset	AM3358BZCZ100; 2000 MIPS	BCM2835; ~2760 MIPS	MK20DX256VL H7 Cortex-M4; 20 MIPS	Allwinner A64 ARM-A53; ~2760 MIPS	Amlogic ARM Cortex-A53; ~4600 MIPS	Low
Operating Voltage	5V	5V	3.3V	5V	5V 2A	Mid
Memory Options	4 GB eMMC Flash	microSD	256 KB inbuilt Flash	microSD	Micro-SD or eMMC5.0	Mid
Size	Medium	Medium	Small	Large	Medium	Mid
Learning Curve	Hard	Medium	Easy	Hard	Hard	High
Clock Speed	1 GHz	1.2 GHz	72 MHz	1.2 GHz	2 GHz	High
RAM	512MB DDR3 SDRAM	1GB LPDDR2	64 kB	2GB DDR3	2GB DDR3 SDRAM	High
Dedicated GPU	Software Rendered	VideoCore IV; 300 MHz	Not Available	2x ARM Mali-400MP2	3x ARM Mali-450MP; 700 MHz	High
Notes:	Lowest amount of support	Overvolt options			Inbuilt IR Receiver	

3.5.0 Camera Considerations

There are several different options when it comes to cameras. Since the camera is mounted on the flight platform a requirement is that it be run off a small microcontroller, covered in section 4.1.3.1. The most flexible options available are the Raspberry Pi 3 Model B, the Pine64, or the ODROID-C2, which are based on Linux. Two cameras may be used to assist in depth and perception mapping. It may be more practical to take snapshots instead of recording video to save memory, power, and processing power, then only using the video capabilities as necessary. For this section as well as Section 4.1.3.3, Software Development, an additional resource is Tung Dao's *Video-Guided Autonomous Pollinator Rotorcraft* [41].

A. *Raspberry Pi's Camera Board* [42]
The Raspberry Pi Foundation has two variants of its in-house designed camera board. Released in February 2016, the cameras feature a Sony IMX219 CCD 8-megapixel camera giving a 3280x2464 pixel photo feed, 1080p 30 frames-per-second (fps) going to 640x480p at 90fps. Along with these specifications, it outputs images in YUV format, and contains some inbuilt auto white balancing (AWB), which will assist in image clarity. Unfortunately, YUV, while highly compressed from raw RGB, has great losses and is inefficient due to the frames containing information meant for black-and-white televisions from the 1950s. [43] An issue however with this camera is that it has a ribbon cable built in, making it difficult for any microcontroller other than the Raspberry Pi 3 Model B to use.

B. *CMUcam5 (Pixy)* [44]
The CMUcam5 (also known as the Pixy) is developed by Charm Labs and Carnegie Mellon University. Using the Hue Saturation Value (HSV) color system, it can track a single color/image or a color map. It has an onboard NXP LPC4330, with an Omnivision OV9715 image sensor capable of 1280x800 pixels. These factors, coupled with its small form factor and multitude of I/O ports make it ideal for this project, but the HSV system is not as useful when identifying missing persons and might only be used for its color mapping for ground personnel to code landmarks and identify key figures since there is a limit of 7 filters per camera stored on its onboard memory.

C. *Off the Shelf Webcam: Logitech C920* [45]
Using a commercial-off-the-shelf (COtS) webcam has its advantages in both versatility and resolution. Using the Linux UVC Project's UVC driver, video4linux, or Empathy, any webcam can be used. This driver is built into Debian based systems natively so the system should be plug and play. The Logitech C920 is a popular camera both in business applications as well as consumer grade vision based tracking experiments. It features a max image resolution of 15 megapixels, a top video capture frame of 1920x1080 pixels at

30 fps, with H.264 compression and onboard white balance. This gives significantly better images than the other cameras. The issue with this camera is that it weighs significantly more than the Pixy or the Raspberry Pi's camera board and has a much higher cost to go with it.

3.6.0 Parts Down Select

A. *Communications Systems*

The communications system is the single most important piece. While there are several options including Bluetooth, LTE, Ka Band, and others, those systems are limited by size and weight constraints, as well as inaccessibility. The combination of 802.11 unlicensed Wi-Fi protocols and Iridium's SBD network allows enough range and speed for information to travel efficiently without having to jump through paperwork allowing for quicker deployment.

B. *Microcontroller*

The microcontroller is the brain of the system. The trade study revealed several different choices, where the ODROID-C2 revealed itself to be a powerhouse in all respects. The final choice turned out to be the Raspberry Pi 3 Model B (see Table 3.5), which was average in all categories, but had a vast assortment of libraries and a thriving community dedicated to the platform to pull from. There are also number of inertial measurement units (IMUs) that are compatible and have prebuilt libraries for this system. If an additional resource is necessary, the possibility for a hybrid system with a Teensy. The Teensy may be an ideal situation due to the smaller footprint and easier coding due to multiple application programing interfaces (APIs) available.

C. *Sensors*

Given that the OpenCV libraries are developed for any platform, any of the cameras can be used. The inclination is to use to Raspberry Pi Foundation's developed camera given that the top microcontroller choice is currently the Raspberry Pi 3 Model B and the camera does not need any additional drivers. However, if at any point the microcontroller changes, then the camera can no longer be used, which leads to choosing the Logitech C920 webcam. The C920 outshines the Pixy, because of its compression format H.264, which is fast and allows for good video playback at a quarter of the original file size. Infrared sensors also scored highly due to low cost and versatility, which can be developed alongside the vision based system.

Table 3.2: Mapping and Surveillance Systems Down Select								
	Accuracy	**Size**	**Availability**	**Cost**	**Volt. Req.**	**Range**	**Accessibility**	**Total**
Weighing	20%	20%	15%	15%	15%	10%	5%	100%
LIDAR	10	8	4	6	8	8	6	74%
RADAR	6	4	10	8	10	10	6	75%
Vision Based Sensor	8	8	10	8	10	6	10	85%
CDGPS	8	8	2	2	4	10	2	55%
Infrared	8	10	6	8	10	6	6	81%

D. *Low Altitude Platform*

For the altitude platform, the only real choice for a long-term aerial vehicle is an inflatable device, more specifically helikites. As outlined in Section 2.3.0, the system is governed by weight, aerodynamic properties, and size. While cost was not expressly stated, having a low-cost vehicle would assist in being able to deploy more systems and setting up a more comprehensive network. The lighter than air vehicle is ideal for these traits given its lower cost of operation, its ability to apply lift without the need for complex control systems, and the ability to manipulate the shape for better stability.

Helikites are helium inflatable kites in an oblate-spheroid shape. The shape is advantageous for the tasks as it allows the body to utilize both helium and wind to achieve lift. In addition to that, the kite and keel are used to provide rigidity and stability to the craft, resisting pressure changes which might otherwise deform a blimp or balloon. While still affected by precipitation and temperature, these concerns are greater than if an active system or balloon were used. The kite and shape allows for mounting points for various sensors and cameras.

Table 3.3: Lift Device Down Select					
	Payload Lift Capabilities	**Durability**	**Ease of Handling**	**Fuel Requirements**	**Total**
Weight	30%	35%	30%	5%	100%
Quadcopter UAV	8	6	4	6	60%
Aircraft	10	8	3	4	69%
Airship	6	6	5	6	57%
Balloon Aerostat	5	2	10	8	56%
Helikite	9	10	8	8	90%

Table 3.4: Safety System Down Select					
	Reliability	**Weight**	**Complexity**	**Durability**	**Total**
Weight	30%	35%	30%	5%	100%
Parachute	6	8	10	5	79%
Autorotator	8	8	8	5	79%
Inflatable Collision	9	7	6	10	75%
Active Propellers	6	8	4	5	61%

In terms of the safety system, parachutes, auto-rotation systems, and inflatable collision devices are all viable options with very different weaknesses. Parachutes and auto-rotators are weak in turbulent and undesirable weather, but are highly reliable at all other times. Parachutes, to minimize size and weight, suffer from complex folding and deployment schemes as well as placement. Inflatable collision devices, while unaffected by weather, may cause damage and injury. Therefore, a combination of devices will be selected which can be seen in the Chapter 5.

E. Gas Choices

The gas choices for these types of vehicle include hydrogen, helium, methane, and hot air, however hydrogen and methane react with air causing explosions, while hot air is unexplored, making helium the only readily available source.

Table 3.5: Microcontroller Board Down Select									
	Cost	Operating Voltage	Memory Options	Size	Learning Curve	Clock Speed	RAM	Dedicated GPU	Total
Weight	5%	5%	10%	10%	15%	20%	20%	15%	100%
BeagleBone Black	8	6	6	8	4	4	4	4	55%
Raspberry Pi 3 Model B	6	6	10	8	8	6	6	6	70%
Teensy 3.2	4	6	4	10	10	2	2	2	19%
Pine A64+	6	6	10	4	2	6	8	8	55%
ODROID-C2	8	6	10	6	4	8	8	10	65%

CHAPTER 4

SURVEILLANCE SYSTEM SOFTWARE DEVELOPMENT

4.1.0 Libraries and Limitations

OpenCV (Open Computer Vision Library), is a set of libraries built for computer vision and machine learning. Part of these libraries includes not only the color recognition functions (converting from RGB to HSV or YUV color schemes as necessary), but also the ability to include feature recognition and people detection (using the Histogram of Orientated Gradients, HOG, algorithm to analyze the image). OpenCV color recognition libraries are already included are already in the CMUcam5, however the library only saves and sets for the center pixel aboard the camera [46]. For these cases, the software needs to be tweaked, with the possibility of adding morphological operators to clean the image and filter false positives. An example of this method can be seen in the flow diagram in Figure 2.

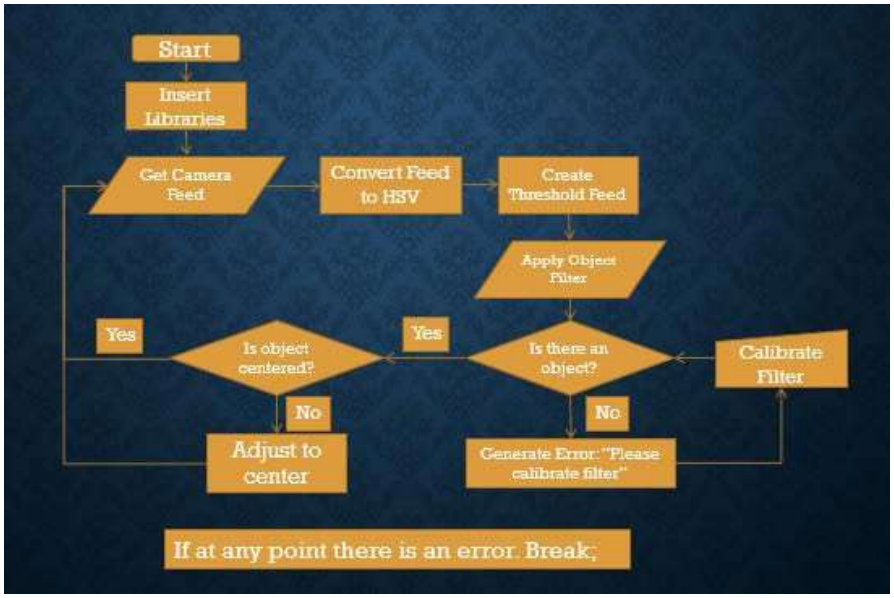

Figure 4.1: Color Blob HSV Programming Flow

These methods can also be utilized within MATLAB, taking advantage of its graphics and stereo vision functions with some differences. The main difference is that the images within MATLAB are represented in a stereo disparity map, which compares features two images at the same point in time. This reduces the need to look at color recognition and instead relies on differences in a composite image. This method is further discussed in Chapter 4.2.

4.2.0 Image Capture Setup

OpenCV assumes a simplified model, which defines θ as the viewing angle of an imaging device of width *w* pixels, object of known height *h*, distance *d*, and has an image height of *i* pixels. In his paper titled, “Video-Guided Autonomous Pollinator Rotorcrafts” Tung then goes onto describe how to find the angular coverage, φ, and the focal length, *f*, which is enough to solve for distance or depth. These equations are listed in Equations (3) through (8). [41]

$$tttttttt = \frac{1}{ff} \tag{4.1}$$

$$ff = \frac{ww}{tttttttt} \tag{4.2}$$

$$tt = \tan^{-1}\frac{ii}{ff} = \tan^{-1}\frac{h}{dd} \tag{4.3}$$

$$\frac{ii}{ff} = \frac{h}{dd} \tag{4.4}$$

$$\frac{ii}{\left(\frac{ww}{tttttttt}\right)} = \frac{h}{dd} \tag{4.5}$$

$$dd = h * \frac{ww}{ii * tttttttt} \tag{4.6}$$

While achievable, Tung's method assumes that all objects are of the uniform height.

MATLAB provides another method of doing this for stereo cameras. After calibrating the cameras using `stereoCameraCalibrator` app or the `estimateCameraParameters` function. With these two functions, a similar process occurs, where a 3D image is mapped onto a 2D image space and written into a matrix. However, at this point a `handshakeStereoParams.mat` file is generated. This file contains camera extrinsic values which can give a visualization on orientation and size of objects.

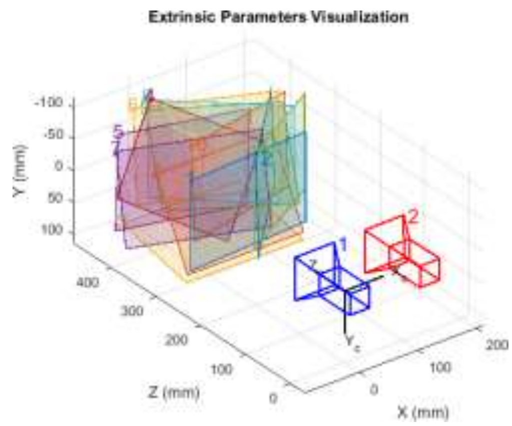

Figure 4.2: Extrinsics Shown using the showExtrinsics Function in MATLAB [47]

While the extrinsics will show all objects in the field, it does not show available objects that might not be part of the background, to do that the video files must be read into the field and a 3D image must be reconstructed. This occurs by matching the points to 1D and rectifying the videos into one. (At this point the images are combined as an anaglyph which can be viewed as 3D using red-cyan 3D glasses.) Using the MATLAB function `disparity,` distance of corresponding pixels is calculated, which can then be used to combined to reconstruct a 3D image using the `reconstructScene` and `pointCloud` functions which looks at both the disparity map and the scene parameters. At this point, there is a 3D

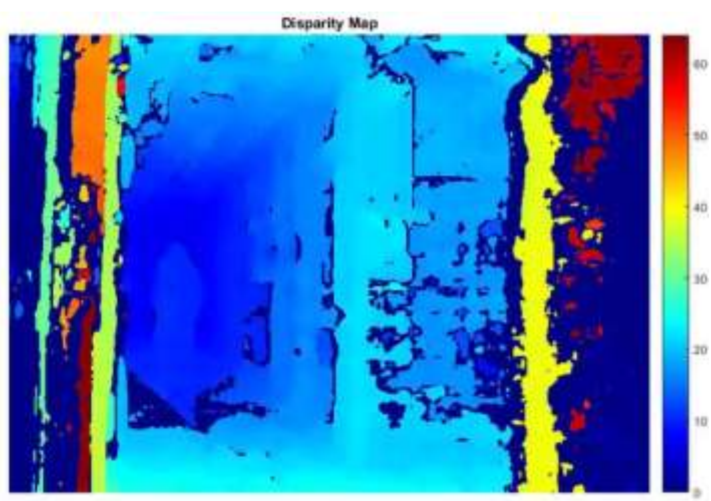

Figure 4.3: Disparity Heatmap using the Disparity Function [47]

landscape constructed by the cameras and, using MATLAB's Computer Vision Toolbox, one can reconstruct and find distances between objects (a sample image using this method can be seen in Figure 4.

Figure 4.4: MATLAB's "People Detector" Function in its Computer Vision Toolbox [47]

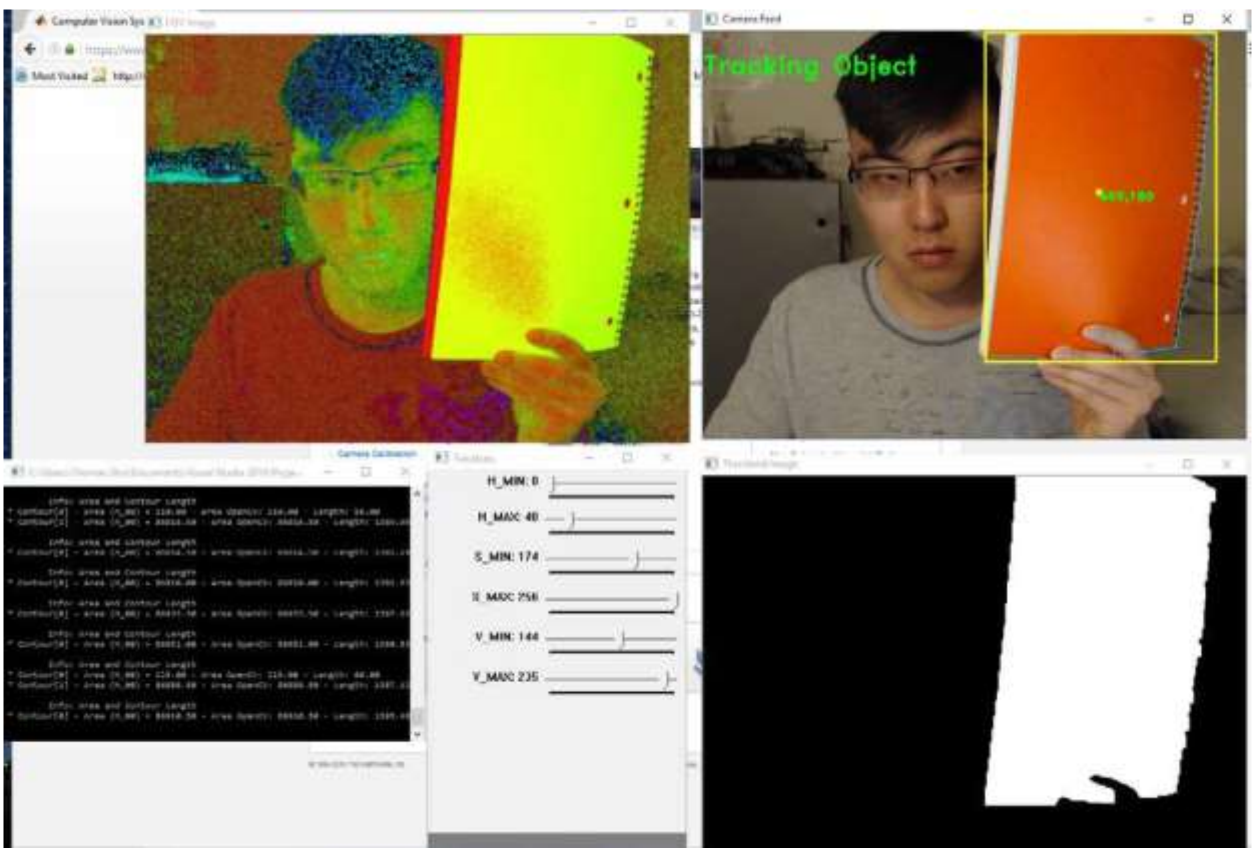

Figure 4.5: HSV Color Filtering for Orange Notebook using OpenCV

4.3.0 Data Reduction

In addition to color mapping and taking images, data reduction techniques can also be applied. Photos and videos take up memory at an alarming rate and may not be entirely relevant as the scenes may be unchanged. Utilizing data reduction techniques, images can be compared against each other to pull key elements and the reduce the number of duplicate images. Points of interest can be flagged and brought to the attention of someone to review and determine whether the images are worth keeping.

CHAPTER 5

ANALYSIS

5.1.0 Mass of the System

Table 5.1 shows a rough estimated cost and weight breakdown for the components of a single system.

Table 5.1: Parts List and Weight Calculations

System	Part	Weight	Cost
Aerial	Microcontroller – Raspberry Pi 3	45g	$35
	Camera – Raspberry Pi Camera V2	3g	$30
	Tether – ULINE 600ft Polypropylene Rope	45359g	$360
	Parachute - Nylon	7000g	$70
	Helikite – Allsopp Desert Star	1360g	Price unavailable
Total Aerial		53767g	$495 (w/o helikite)
Terrestrial	Data Storage and Access	2500g	$600
	SBD Unit - Iridium	11.4g	$50
	GPS Unit – Adafruit Ultimate GPS	8.5g	$40
Total Terrestrial		2520g	$690
Complete Total		56287g	$1185 (w/o helikite)

Summarizing the table, the weight of the aerial components is 54 kg (120 lbs) and the terrestrial portion weighing 2.5 kg (5.5 lbs); totaling 56 kg (126 lbs).

5.2.0 Helikite Sizing

The sizing of the helikite is determined by the gas choice and the weight of the aerial portion. Given that the appropriated material for this is helium our final weight and considerations are based on that. The calculations for gas utilizes Archimedes' Principle (the weight of the displaced fluid must be greater than the weight of the object for it to provide lift.) Using the mass found in Table 5.1, our aerial components are approximately 54 kg and would take 529.2 Newtons to lift the system. This translates to 53 m^3 of helium at standard temperature and pressure (STP) under pure helium lift and ideal conditions. This however is unreliable, so a factor of safety of 1.5 is applied, which approximates to 80 m^3 of helium.

Archimedes Principle:

$$DDDDttDDiittDD\ ooff\ ttiiaa = 1.2\,\frac{kkkk}{mm^3} \tag{5.1}$$

$$DDDDttDDiittDD\ ooff\ HHDDiiHHmm = 0.1787\,\frac{kkkk}{mm^3} \tag{5.2}$$

$$\frac{mm}{\rho\rho_{aaaaaa} - \rho\rho_{heeeeeeee}} = VVooHHmmDD\ ooff\ HHDDiiHHmm \tag{5.3}$$

$$\frac{54\ kkkk}{1.2\,\frac{kkkk}{mm^3} - 0.1787\,\frac{kkkk}{mm^3}} = 52.874\ mm^3\ ooff\ HHDDiiHHmm \tag{5.4}$$

5.3.0 Safety System Sizing

Parachute:

Parachutes can easily control descent speed and have less moving parts than any other system in terms of recovery options. While a parachute can be made of any number of materials, there are only a few that can support larger opening forces of a 54 kg system. Cloth like materials work best such as cotton, silk, polyester, or nylon. According to Apogee Component's guide to sizing and designing parachutes for rockets, a descent velocity of 3.5 to 4.5 m/s is ideal. [48] The general formula for determining the surface area of a parachute is:

$$S = \frac{n}{4} * D^2 * \tan\left(\frac{180°}{n}\right) \tag{5.5}$$

Where D is the distance across the flats of the polygon and n is the number of sides in the polygon. This equation can be estimated for a round canopy with a circular parachute shape in which case, the formula becomes:

$$S = \frac{2mg}{\rho C_d V^2} \tag{5.6}$$

$$D = \sqrt{\frac{4S}{\pi}} \tag{5.7}$$

Given that:

- C_d = 0.75 ([2])
- ρ = 1.225 kg/m^3
- g = 9.81 m/s^2

$$S = \frac{2\left(9.81\frac{m}{s^2}\right)(54kg)}{\left(\frac{1.225kg}{m^3}\right)(1.75)4.5^2} \tag{5.8}$$

$$S = 56.947\ m^2 \tag{5.9}$$

$$D = \sqrt{\frac{4 * 56.947\ m^2}{\pi}} \tag{5.10}$$

$$D = 8.515\ m \tag{5.11}$$

This gives an overall area of 57 m^2 and a circular diameter of 8.5 m. After applying our factor of safety, the approximate area is 86 m^2 and approximate diameter is 13 m.

Inflatable Collision:

Inflatable collision devices work despite weather conditions being unfavorable and would be ideal to have as a secondary system in case the primary system fails. Inflatable collision systems operate similarly to automobile airbags and can be arranged similarly to the airbag system for the Pathfinder, Spirit, and Opportunity rover landing systems. The arrangement is due

[2] Assuming round canopy in steady state conditions with 0 angle of attack. [56]

to the rocks and various other debris that may be located on the ground. Like the rovers, the collision system could be made of interconnected spheres and various layers to prevent puncturing the inflatable bladders.

Sizing for this system can be calculated using parameters set for automobile airbags, where the airbags begin at rest and has a velocity of 89.4 m/s just before it is completely full. The airbag weighs 2.5 kg per sphere has a travel distance of 30 cm. Acceleration and force on the bag can be found using Newton's Laws of Motion and the Kinematic Equations.

$$vv_{ff}^2 - vv_{aa}^2 = 2ttdd \quad (5.12)$$

$$\left(89.4\frac{mm}{DD}\right)^2 - 0 = 2(tt)(0.3\ mm) \quad (5.13)$$

$$tt = 1.33(10^4)\frac{mm}{ss^2} \quad (5.14)$$

$$FF = mmtt \quad (5.15)$$

$$FF = 2.5\ kkkk * 1.33(10^4) \quad (5.16)$$

$$FF = 3.33(10^4)\ NN \quad (5.17)$$

The acceleration of the front of each sphere is approximately 13300 m/s^2, which departs a force of 33300 N.

CHAPTER 6

OPERATIONS

6.1.0 Concept of Operations

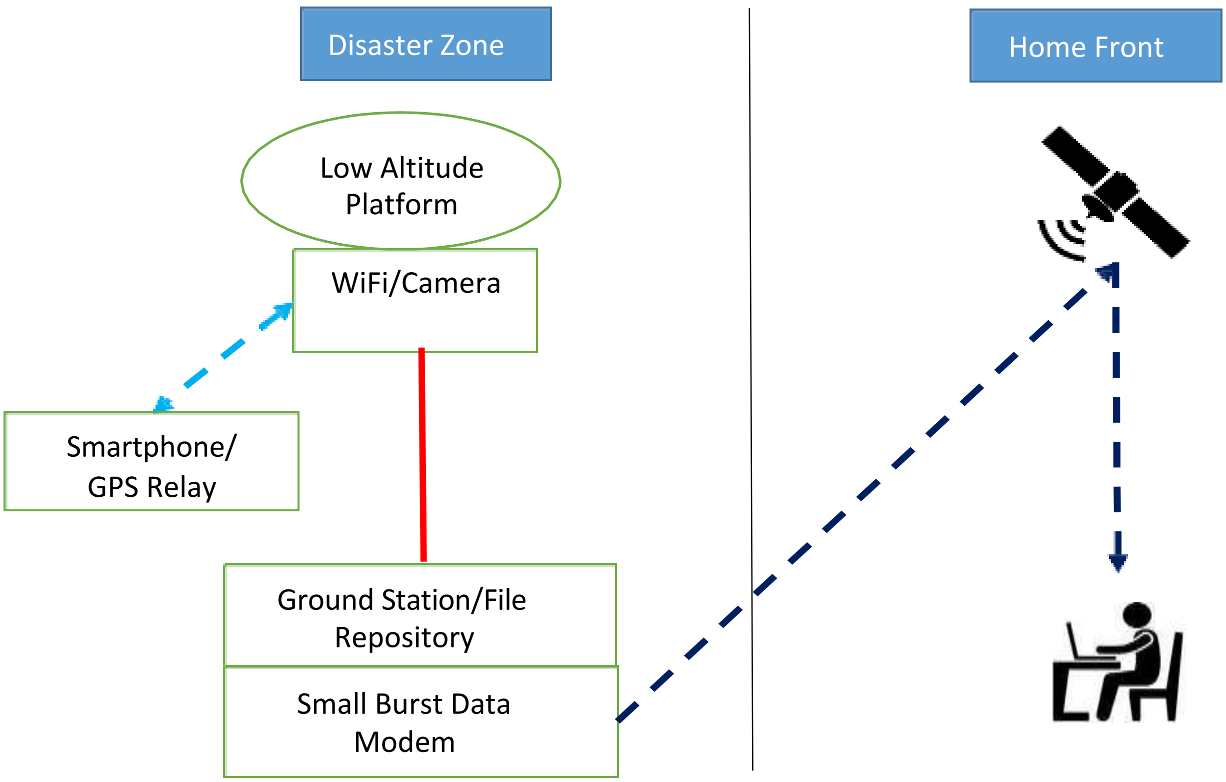

Figure 6.1: Project Canvas Concept

This project will work on two fronts, one at the disaster zone and one at the home front. As described in Chapter 3, the LAP will hold the 802.11 antenna equipment as well as the surveillance system. The LAP will broadcast to surrounding stations to set up a mesh network and a local intranet. These systems will then provide useful data to ground personnel working in the field via smart phone or other devices capable of accessing the appropriate frequencies. This intranet will allow users to share data across the region and access surveillance footage that will be useful in moving towards high damage areas. Personnel carrying smartphones or GPS relays can use the aerial vehicles as waypoints as check in locations, which will further assist in the coordination of personnel, improve efficiency, and safety. In addition to the LAP, a SBD service will be available at ground stations. While only capable of 150 bytes, this is enough to send out GPS coordinates as well as a person's name, which is immensely useful in diverting concerned family members from clogging emergency service lines to reading information quickly and succinctly from a webpage, which can handle far more traffic.

6.2.0 Deployment Plan

Deployment plans are often difficult because one needs to weigh risk versus benefit. Ideally for this project, there would be no limitations where Project Canvas is airdropped and is deployed midair without harming people or upsetting the disaster area. However, this is improbable. What is more likely is that ground personnel will unload these systems with other critical equipment. As personnel sets up safe point and moves out radially from those points. As personnel staff moves to the edge of one safe zone, the system is deployed far enough from a previous station that can survey the outlying region before personnel move, but close enough that it can still connect reliably with a pervious station.

6.3.0 Risk Factors and Mitigation

There are inherent risks associated with working in a disaster zone despite precautions. In Table 6.1, a risk matrix is developed on a scale from one to five, where 1 is very low and 5 is very high. The X axis (going horizontal) describes impact, while on the Y axis (vertical) describes likelihood. Table 6.1 displays risks and mitigations for this project.

Table 6.1: Risk Matrix					
5	A5	B5	C5	D5	E5
4	A4	B4	C4	D4	E4
3	A3	B3	C3	D3	E3
2	A2	B2	C2	D2	E2
1	A1	B1	C1	D1	E1
Likelihood ^ Impact >	A	B	C	D	E

Table 6.2: Risks and Mitigations for Project Canvas

Cell Number	Issue	Mitigation
E3	Network security breach into the LAPs	256-bit AES encryption on the data storage devices
C3	Turbulent weather causing bad connections	Passively stabilized aero body and changing altitudes
C4	Falling out of the sky / Bad Weather	Various safety systems
B4	Part failure	Debugging ports on ground base station to see if the failure if fixable

CHAPTER 7

KEY CONCERNS AND CONSIDERATIONS

While this paper introduces a system level design for the future of wireless safety, there are still major challenges and issues. Weight and cost are still major concerns; at over 50 kg and $1185, the weight is too much for a single person to carry and too expensive per unit. Weight can be addressed with advanced materials such as Vectran, Dyneema, or carbon fiber weaving, which have stronger tensile strength, which would require less material for a tether. A lighter tether weight would also decrease material needed for the parachute and the size of the helikite. Cost can be mitigated by mass production. Another concern is security, M.I. Channa and K.M. Ahmed discuss in the paper, "Emergency Response Communications and Associated Security Challenges" the trials associated with securing wireless ad hoc networks including data integrity, authentication and management, and proposed frameworks. [49] Range and longevity is also a key concern moving forward. 802.11 wireless protocol is currently the best solution given its unlicensed nature, however the range and its susceptibility to interference means that it will have to be monitored. An unlicensed LTE (LTE-U) network may be a better solution, however broad availability and reliability have yet to be achieved. Eventually, this project hopes to move away from hobby components, such as the Raspberry Pi platform, which may be susceptible to quality control issues. Custom circuit boards are another research topic that must be considered moving forward.

CHAPTER 8

CONCLUSION

When faced with a disaster, many things come into play: how to reconnect families with loved ones, to find a safe place to house people, to organize search and rescue parties, and to coordinate with international groups attempting to assist or to learn more; without an effective communications system, none of this is possible. Project Canvas proposes an all-in-one solution working on several different levels including, assisting in rescue operations, building temporary infrastructure, and informing the public on unfolding events. This paper proposes a system level design and an implementation method for future work to be built on.

CHAPTER 9

FUTURE WORK

The next step of this project is to characterize wireless transmission signals over the aerostat design, including weather effects, aerostat dynamics, and overall range.
Weight reduction techniques, data reduction, and portable form factors will also have to be considered. Further considerations include live testing, development of custom parts, and programmatic training.

Recently technologies have been attempting to match the growing danger of natural and man-made disasters. Wireless ad-hoc networks (WANET or MANET) are receiving greater exposure and are being developed into aerial systems. Formal projects such as Northrop Grumman's Battlefield Airborne Communications Network (BACN) and the NYCWiN both utilize aerial coverage systems to better supplement current solutions. Satellite technology is also advancing, where projects such as the Transformational Satellite (TSAT) Communications Systems [50] and Google's Project Loon [51] attempt to bring broadband internet to everyday users without the need for traditional free-standing structures. Independent researchers are also proposing various low altitude platform, such as ABSOLUTE [52] [53], EBAN [54], etc. Each of those projects has its own boons and challenges, many of which are the same as Project
Canvas's. The work will continue, in hopes of reducing casualties in the future.

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Appendix A: Object Tracking Code

```
//SingleObjectTracking.cpp
//Written by Thomas Shu 04-02-2017
//Influenced by Kyle Hunslow

#include <sstream>
#include <string>
#include <iostream>
#include <opencv\highgui.h>
#include <opencv\cv.h>

using namespace cv;
using namespace std;

//initial min and max HSV filter values.
int H_MIN = 0;
int H_MAX = 256;
int S_MIN = 0;
int S_MAX = 256;
int V_MIN = 0;
int V_MAX = 256;

//default capture width and height
const int FRAME_WIDTH = 640;
const int FRAME_HEIGHT = 480;

//max number of objects to be detected in frame
const int MAX_NUM_OBJECTS=50;

//minimum and maximum object area
const int MIN_OBJECT_AREA = 20*20;
const int MAX_OBJECT_AREA = FRAME_HEIGHT*FRAME_WIDTH/1.5;

//Create Name for Trackbars
const string trackbarWindowName = "Trackbars";

RNG rng(12345); //for bounded rectangles


void on_trackbar( int, void* )
{//This function gets called whenever a
        // trackbar position is changed

}
string intToString(int number)
{
        stringstream ss;
        ss << number;
        return ss.str();
}

// create window for trackbars
void createTrackbars()
{
  namedWindow(trackbarWindowName,0);
```

```
	//create memory to store trackbar name on window
	char TrackbarName[50];
	sprintf( TrackbarName, "H_MIN", H_MIN);
	sprintf( TrackbarName, "H_MAX", H_MAX);
	sprintf( TrackbarName, "S_MIN", S_MIN);
	sprintf( TrackbarName, "S_MAX", S_MAX);
	sprintf( TrackbarName, "V_MIN", V_MIN);
	sprintf( TrackbarName, "V_MAX", V_MAX);

	//create trackbars and insert them into window
	//3 parameters are: the address of the variable that is changing when the trackbar is moved(eg.H_LOW),
	//the max value the trackbar can move (eg. H_HIGH),
	//and the function that is called whenever the trackbar is moved(eg. on_trackbar)
	//                              ---->    ---->     ---->
   createTrackbar( "H_MIN", trackbarWindowName, &H_MIN, H_MAX, on_trackbar );
   createTrackbar( "H_MAX", trackbarWindowName, &H_MAX, H_MAX, on_trackbar );
   createTrackbar( "S_MIN", trackbarWindowName, &S_MIN, S_MAX, on_trackbar );
   createTrackbar( "S_MAX", trackbarWindowName, &S_MAX, S_MAX, on_trackbar );
   createTrackbar( "V_MIN", trackbarWindowName, &V_MIN, V_MAX, on_trackbar );
   createTrackbar( "V_MAX", trackbarWindowName, &V_MAX, V_MAX, on_trackbar );
}

void drawObject(int x, int y,Mat &frame)
{
	circle( frame, Point(x,y), 4, Scalar(0,255,255), -1, 8, 0 ); //use if you want single dot at center of tracked object
	putText(frame,intToString(x)+","+intToString(y),Point(x,y+10),1,1,Scalar(0,255,0),2); //display coordinates
}

void morphOps(Mat &thresh)
{
	//create structuring element that will be used to "dilate" and "erode" image.
	//the element chosen here is a 3px by 3px rectangle
	Mat erodeElement = getStructuringElement( MORPH_RECT,Size(3,3)); //4x4 gives reliable hand

	//dilate with larger element so make sure object is nicely visible 8x8
	Mat dilateElement = getStructuringElement( MORPH_RECT,Size(8,8)); // 4x4 gives reliable hand

	erode(thresh,thresh,erodeElement);
	erode(thresh,thresh,erodeElement);

	dilate(thresh,thresh,dilateElement);
	dilate(thresh,thresh,dilateElement);

}
void trackFilteredObject(int &x, int &y, Mat threshold, Mat &cameraFeed)
{
	Mat temp; //Mat = matrix
	threshold.copyTo(temp);
	//these two vectors needed for output of findContours
	vector< vector<Point> > contours;
	vector<Vec4i> hierarchy;
	//find contours of filtered image using openCV findContours function
	findContours(temp,contours,hierarchy,CV_RETR_CCOMP,CV_CHAIN_APPROX_SIMPLE );

	/// Approximate contours to polygons + get bounding rects and circles
	vector<vector<Point> > contours_poly( contours.size() );
	vector<Rect> boundRect( contours.size() );
```

```
        vector<Point2f>center( contours.size() );
        vector<float>radius( contours.size() );

        for( int i = 0; i < contours.size(); i++ )
        {
                approxPolyDP( Mat(contours[i]), contours_poly[i], 3, true );
                boundRect[i] = boundingRect( Mat(contours_poly[i]) );
                minEnclosingCircle( (Mat)contours_poly[i], center[i], radius[i] );
        }


        //use moments method to find our filtered object
        double refArea = 0;
        bool objectFound = false;

        /// get moments
        vector<Moments> mu(contours.size() );
        for( int i = 0; i < contours.size(); i++)
        {
                mu[i] = moments( contours[i],false );
        }

        /// get mass centers
        vector<Point2f> mc( contours.size() );
        for(int i = 0; i< contours.size(); i++)
        {
                mc[i] = Point2f( mu[i].m10/mu[i].m00 , mu[i].m01/mu[i].m00);
        }

        if (hierarchy.size() > 0)
        {
                int numObjects = hierarchy.size();
    //if number of objects greater than MAX_NUM_OBJECTS we have a noisy filter
    if(numObjects<MAX_NUM_OBJECTS)
                {
                        for (int index = 0; index >= 0; index = hierarchy[index][0])
                        {
                                Moments moment = moments((cv::Mat)contours[index]);
                                double area = moment.m00;

                                //if the area is less than 20 px by 20px then it is probably just noise
                                //if the area is the same as the 3/2 of the image size, probably just a bad filter
                                //we only want the object with the largest area so we safe a reference area each
                                //iteration and compare it to the area in the next iteration.
        if(area>MIN_OBJECT_AREA && area<MAX_OBJECT_AREA && area>refArea)
                                {
                                        x = moment.m10/area;
                                        y = moment.m01/area;
                                        objectFound = true;
                                        refArea = area;
                                }

                                else objectFound = false;

                        }

                        //let user know you found an object
                        if(objectFound == true)
```

```
                {
                        putText(cameraFeed,"Tracking Object",Point(0,50),2,1,Scalar(0,255,0),2);
                        //draw object location on screen
                        drawObject(x,y,cameraFeed);
                }

            }
            else putText(cameraFeed,"TOO MUCH NOISE! ADJUST FILTER",Point(0,50),1,2,Scalar(0,0,255),2);
        }
        // Calculate the area with the moments 00 and compare with the result of the OpenCV function
        printf("\t Info: Area and Contour Length \n");
        /*
        for( int i = 0; i< contours.size(); i++ )
        {
            circle( cameraFeed, mc[i], 4, Scalar(0,255,255), -1, 8, 0 );
            putText(cameraFeed,intToString(x)+","+intToString(y),Point(x,y+10),1,1,Scalar(0,255,0),2);
        }
        */
        /// Draw polygonal contour + bonding rects + circles
        for( int i = 0; i < contours.size(); i++)
        {
            Scalar color = Scalar( rng.uniform(0, 255), rng.uniform(0,255), rng.uniform(0,255) );
            drawContours( cameraFeed, contours_poly, i, color, 1, 8, vector<Vec4i>(), 0, Point() );
            rectangle( cameraFeed, boundRect[i].tl(), boundRect[i].br(), Scalar(0,255,255), 2, 8, 0 );
            printf(" * Contour[%d] - Area OpenCV: %.2f\n", i,contourArea(contours[i]), true );

            if(contourArea(contours[i]) > 10000)
            {
                //print on screen "Too Close"
                putText(cameraFeed, "Too Close", Point(x,y+30),1,1,Scalar(0,255,0),1);
            }
            else
            {
                // print on screen "Too Far"
                putText(cameraFeed, "Too Far", Point(x,y+30),1,1,Scalar(0,255,0),1);
            }
        }
}

int main(int argc, char* argv[])
{
        //some boolean variables for different functionality within this program
   bool useMorphOps = true;        //MorphOps always true for better area
        bool trackingEnabled = false; //hide until we want it
        bool debugMode = false;                 //hide cause it's ugly
        bool pause = false;                     //just in case we want to look at something

        //Matrix to store each frame of the webcam feed
        Mat cameraFeed;
        //matrix storage for HSV image
        Mat HSV;
        //matrix storage for binary threshold image
        Mat threshold;
        //x and y values for the location of the object
        int x=0, y=0;
        //create slider bars for HSV filtering
        createTrackbars();
        //video capture object to acquire webcam feed
```

```
VideoCapture capture;
//open capture object at location zero (default location for webcam)
capture.open(0);

//if can't get video
if(!capture.isOpened())
{
	cout<<"ERROR ACQUIREING VIDEO FEED\n";
	getchar();
	return -1;
}

//set height and width of capture frame
capture.set(CV_CAP_PROP_FRAME_WIDTH,FRAME_WIDTH);
capture.set(CV_CAP_PROP_FRAME_HEIGHT,FRAME_HEIGHT);

//start an infinite loop where webcam feed is copied to cameraFeed matrix
//all of our operations will be performed within this loop
while(1)
{
	//store image to matrix
	capture.read(cameraFeed);
	//convert frame from BGR to HSV colorspace
	cvtColor(cameraFeed,HSV,COLOR_BGR2HSV);
	//filter HSV image between values and store filtered image to
	//threshold matrix
	inRange(HSV,Scalar(H_MIN,S_MIN,V_MIN),Scalar(H_MAX,S_MAX,V_MAX),threshold);
	//perform morphological operations on thresholded image to eliminate noise
	//and emphasize the filtered object(s)
	if(useMorphOps)
	{
		morphOps(threshold);
	}

	//pass in thresholded frame to our object tracking function
	//this function will return the x and y coordinates of the
	//filtered object
	if(trackingEnabled)
		trackFilteredObject(x,y,threshold,cameraFeed);

	//show feeds
	imshow("Camera Feed",cameraFeed);

	/// Debug Mode on = show HSV and Threshold
	if(debugMode==true)
	{
		//show the HSV Image and Threshold image
		cv::imshow("HSV Image",HSV);
		cv::imshow("Threshold Image",threshold);
	}
	else
	{
		//if not in debug mode, destroy the windows so we don't see them anymore
		cv::destroyWindow("HSV Image");
		cv::destroyWindow("Threshold Image");
	}

	//delay 30ms so that screen can refresh.
```

```
					//image will not appear without this waitKey() command
					//create toggle switches for everything
					switch(waitKey(30))
					{
						case 27: //'esc' key has been pressed, exit program.
							return 0;
						case 116: //'t' has been pressed. this will toggle tracking
							trackingEnabled = !trackingEnabled;
							if(trackingEnabled == false) cout<<"Tracking disabled."<<endl;
							else cout<<"Tracking enabled."<<endl;
							break;
						case 100: //'d' has been pressed. this will debug mode
							debugMode = !debugMode;
							if(debugMode == false) cout<<"Debug mode disabled."<<endl;
							else cout<<"Debug mode enabled."<<endl;
							break;
						case 112: //'p' has been pressed. this will pause/resume the code.
							pause = !pause;
							if(pause == true)
							{
								cout<<"Code paused, press 'p' again to resume"<<endl;
								while (pause == true)
								{
									//stay in this loop until
									switch (waitKey())
									{
										case 112:
											//change pause back to false
											pause = false;
											cout<<"Code Resumed"<<endl;
									}
								}
								break;
							}

						return 0;
					}

				}
			}
```

Appendix B: Acknowledgements

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