Brigham Young University
AUVSI Capstone Team (Team 45)

Concept Development Artifacts

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AUVSI Capstone Team (Team 45)

Capstone Project Contract

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Revision History

ID	Rev.	Date	Description	Author	Checked By
PC-444	1.0	10-02-2018	Opportunity development initial stage	Andrew Torgesen	Kameron Eves & Ryan Anderson & Jacob Willis & Tyler Critchfield & John Akagi
PC-444	1.1	10-17-2018	Added Key Success Measure explanations	Andrew Torgesen	Jacob Willis

Introduction

Each year, the Association for Unmanned Vehicle Systems International (AUVSI) hosts a Student Unmanned Aerial Systems (SUAS) competition. While each year's competition has unique challenges, the general challenge is to build an Unmanned Aerial System (UAS) capable of autonomous flight, object detection, and payload delivery. This year's competition will be held June 12^{th} to 15^{th}, 2019 at the Naval Air Station in Patuxent River, Maryland.

The UASs entered into the competition are judged primarily on their mission success during the competition. Each team is also required to submit both a report and a flight readiness review presentation. The report should justify the UAS decision, explain design trade-offs, demonstrate the team's engineering process, and highlight the capabilities of the UAS. The flight readiness review presentation demonstrates that the UAS is capable of safely completing the competition. The overall score for a team is based on a combination of the points from the mission, report, and presentation.

For the last two years BYU has sponsored an AUVSI team to compete in the competition. The 2017 team was primarily volunteer based and placed 10^{th} overall while the 2018 team was a Capstone team and placed 9^{th} overall. This year's team is also a Capstone team consisting of BYU Mechanical, Electrical, and Computer Engineering students and looks to place as one of the top five teams.

Project Objective Statement

Improve upon last year's BYU AUVSI unmanned aerial system (UAS) by improving path planning, obstacle avoidance, visual object detection, and payload delivery by April 1, 2019 with a budget of $3,500 and 2,500 man hours.

Contact Information

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Project Approval Matrix

The Project Approval Matrix, as depicted in Table 1, lists the major stages of development for the project, as well as their due dates and constituent artifacts. A budget is also included for each stage.

Table 1: Project Approval Matrix for the UAS

Development Stage	**Expected Completion Date**	**Design Artifacts Required for Approval**	**Budget**
Opportunity Development	October 5, 2018	Project Contract System Requirement Matrix Last Year Results Scoring Breakdown	$100
Concept Development	November 2, 2018	Description of Vision Concept Description of Unmanned Ground Vehicle (UGV) Concept Description of Airframe Concept Test Procedures and Results Concept Selection Matrices Subsystem Interface Definitions	$500
Subsystem Engineering	January 18, 2019	Wiring Diagram Vision Logic Diagram Autopilot Logic Diagram Bill of Materials UGV CAD Model UGV Drop Model Subsystem Requirement Matrices Subsystem Test Procedures and Results	$2,000
System Refinement	March 22, 2019	Refined Integrated System Definition System Requirement Matrix UGV Engineering Drawings Refined Bill of Materials Integrated System Test Procedures and Results	$800
Final Reporting	April 1, 2019	Final Report Compilation Flight Readiness Video Technical Design Paper Safety Pilot Log Team Promotional Video	$100

Key Success Measures

We developed a system requirements matrix in conjunction with the AUVSI competition rules (see artifact RM-001). All system-wide performance measures were considered, and five measures listed in Table 2 were selected as key success measures. Over the course of the next two semesters, we will gauge the desirability of our product based on how well the product completes each of these performance measures. Each performance measure will be evaluated in an environment designed to mimic the competition.

Table 2: Key success measures for the UAS

Measures (units)	Stretch Goal	Excellent (A)	Good (B)	Fair (C)	Lower Acceptable	Ideal	Upper Acceptable
Obstacles Hit (#)	0	1	3	5	0	0	5
Average Waypoint Proximity (ft)*	5	20	25	30	0	0	100
Characteristics Identified (%)**	80	40	30	20	20	100	100
Airdrop Accuracy (ft)	5	25	50	75	0	0	75
Number of Manual Takeovers	0	1	2	3	0	0	3

* *Average Waypoint Proximity* refers to the norm of the distance between the UAS and the waypoint location at the point when the autopilot considers the waypoint to be captured.

** *Characteristics Identified* refers to the ability to classify the color, shape, and textual content of visual targets scattered on the ground using camera measurements.

Change Management Procedure

An Engineering Change Order (ECO) will be used to facilitate the proposal, approval, and implementation of any future changes to this contract. The ECO template is found on page 249 of the Product Development Reference (Mattson and Sorenson). A change is initiated by filling out the template and submitting it to all involved parties for approval. Upon unanimous approval, this contract will be edited, the version number will be changed, and the revision history section will be updated with the relevant information, including a reference to the ECO created.

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UAS Requirements Matrix

ID	Rev.	Date	Description	Author	Checked By
RM-001	0.1	09-07-2018	Fall camp draft	Brady Moon	Jacob Willis
RM-001	0.2	09-14-2018	Revisions after design review	Derek Knowles	Kameron Eves
RM-001	1.0	10-08-2018	Expansion for stage approval	Kameron Eves	Brandon McBride
RM-001	1.1	10-08-2018	Reordered requirements to match priority	Jacob Willis	Brady Moon
RM-001	1.2	10-17-2018	Fixed inconsistency in autonomous flight requirement	Andrew Torgesen	Kameron Eves
RM-001	1.3	11-08-2018	Added Target Values	Kameron Eves	[Checker]

Product: UAS
Subsystem: N/A

Notes:
UAS = Unmanned Aerial System
UGV = Unmanned Ground Vehicle

#	Market Requirements	Importance	Market Responce
1	The UAS shall be capable of autonomous flight.	20%	Very Good
2	The UAS shall be capable of avoiding static obstacles.	20%	Very Good
3	The UAS shall be capable of visual object classification.	20%	Very Good
4	The UAS shall be capable of delivering a payload.	20%	Very Good
5	The UAS shall be capable of safe operation.	10%	Good
6	The UAS shall be capable of a timely completion of the mission.	10%	Good

Target Values	Upper Acceptable	Ideal	Lower Acceptable	Importance	MR 6	MR 5	MR 4	MR 3	MR 2	MR 1	#	Performance Measures	Units
20	40	20	3	6%	●						1	Flight Time	Minutes
0	10	0	0	2%	●						2	Post Processing Time	Minutes
20	40	20	3	8%						●	3	Autonomus Flight Time	Minutes
100	100	100	0	2%						●	4	Percent of Waypoints Hit	Percent
5	100	0	0	10%		●	●			●	5	Average Minimum Distance to Waypoint	Feet
0	100	0	0	20%					●	●	6	Percent of Obstacles Hit	Percent
80	100	100	0	4%				●			7	Percent of Correct Characteristics Identified	Percent
100	100	100	0	6%				●			8	Percent of Images Correctly Geolocated	Percent
100	100	100	0	6%	●			●			9	Percent of Objects Submitted in Flight	Percent
100	100	100	0	4%				●		●	10	Percent of Objects Autonomously Submitted	Percent
5	75	5	0	10%			●				11	Payload Drop Distance to Target Location	Feet
5	10	0	0	10%			●				12	UGV Stop Distance to Target Location	Feet
Y	Y	Y	Y	10%		●					13	Complies with AMA Safety Code	Yes/No
0	15	0	0	2%	●	●	●	●	●	●	14	Penalties	Count

Figure 1: Top-level requirements matrix for the unmanned aerial system. Performance measures that are marked in grey are our key success measures. Note that cumulatively, our key success measures account for 46% of the possible points.

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UAS Subsystem Interface Definition

ID	Rev.	Date	Description	Author	Checked By
SS-001	0.1	10-25-2018	initial draft	Andrew Torgesen	Jake Johnson & John Akagi
SS-001	0.2	10-30-2018	adjusted wording	Andrew Torgesen	Kameron Eves
SS-001	1.0	10-30-2018	adjusted diagram	Andrew Torgesen	Brady Moon
SS-001	1.1	11-05-2018	added introduction and fixed typos	Andrew Torgesen	Brady Moon

1 Introduction

At its heart, the AUVSI competition is a systems engineering competition, testing how well a team can bring together a complex amalgamation of software and hardware components to accomplish sophisticated tasks in autonomy and aviation. While no key success measure directly measures this integration, all of the key success measures are acheived through adequate system integration. Thus, as part of the Concept Development process for the UAS, proper interface protocols must be defined so that inter-component testing can commence as soon as possible. Upon identifying the most critical subsystem interfaces, tests may be designed to evaluate the effectiveness of our chosen means of communicating between subsystems.

2 Subsystem Interfaces

Figure 1 gives a top-level description of the major hardware and software subsystems, as well as how they interface in the fully-functioning UAS. Table 1 lists descriptions of the functions of each software component listed in the figure.

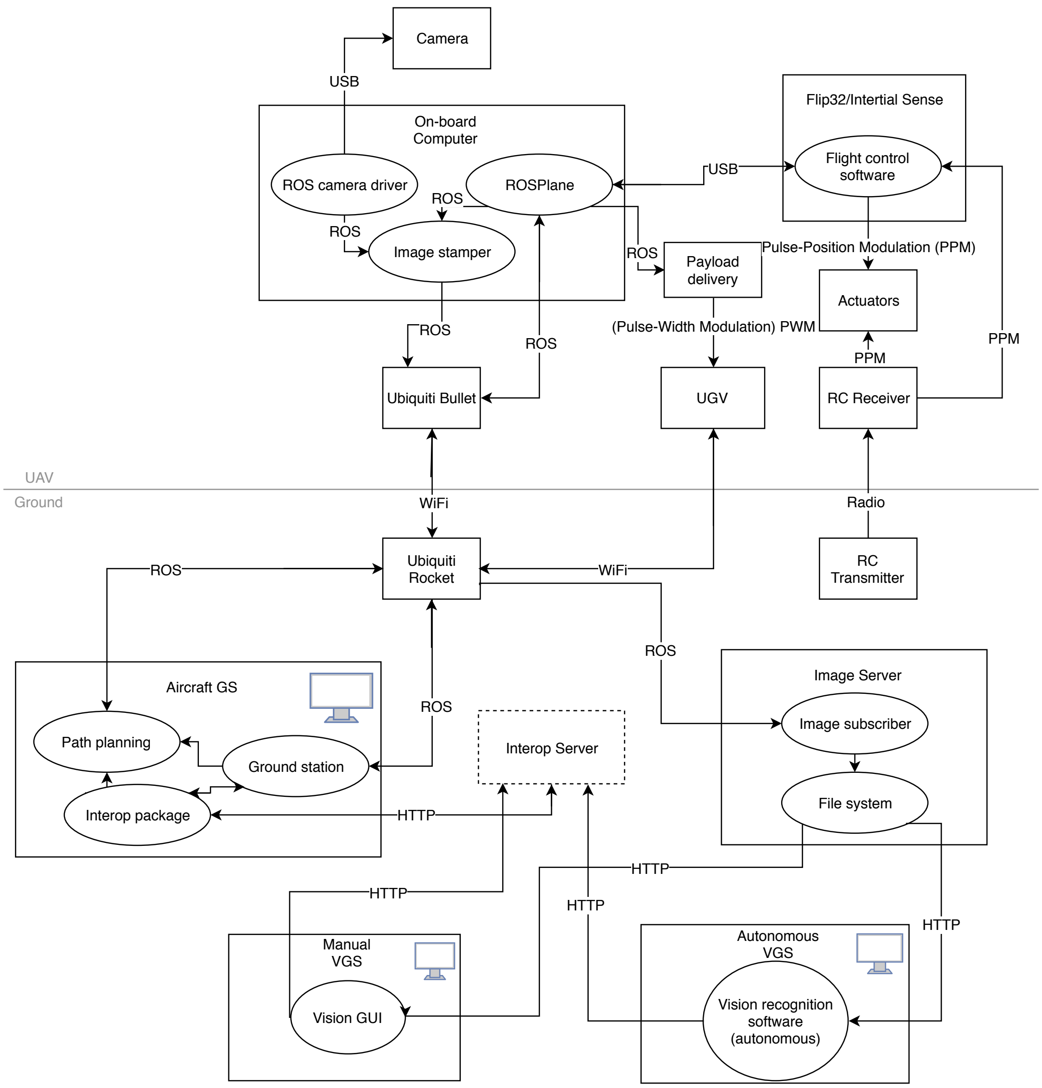

Figure 1: System-wide interface diagram for the UAS. Hardware is denoted by a box, and software is denoted by an oval.

Table 1: Descriptions of the functions of the software components listed in Figure 1.

Software Component	Description
ROS camera driver	Reads the serial input from the camera and streams it as ROS messages so other ROS programs have access to the camera images in real time.
ROSPlane	Top-level autopilot. Takes a set of waypoints and converts them into low-level commands to be interpreted by the flight control software. Also constructs a state vector containing all of the dynamic states of the UAS.
Image stamper	Takes streamed camera images and stamps them with time and UAS state data. This facilitates subsequent geolocation of objects found in each image.
Flight control software	Converts low-level autopilot commands into actuation commands and reads in sensor data. Consists of: • ROSFlight: handles autopilot commands, reads in airspeed and barometer data • Inertial Sense: reads in GPS and inertial sensor data
Path planning	Given the details of the competition (including obstacle and flight area data), plans a series of waypoints for the UAS.
ground station	Allows for the visualization of the UAS and provides an interface for sending waypoint, loiter, and return-to-home commands.
Interop package	Communicates with the judges' interop server, and serves up competition details over the ROS network. Also reports UAS data back to the judges' server.
Image subscriber	Captures streamed camera images from the ROS network.
File system	Stores images from Image subscriber on the computer's file system for direct HTTP access by ground station computers.
Vision GUI	Provides an interface for the manual classification of targets in images, as well as reporting the classification data to the judges' server.
Vision recognition software (autonomous)	Runs computer vision software that autonomously classifies targets in images and reports the results to the judges' server.

3 Conclusion

As can be seen from Figure 1, both radio and WiFi will be used to facilitate connection between the subsystems on the ground and in the air. The Ubiquiti data link allows for communication between the ground and the aircraft over a WiFi network. A 2.4 GHz radio link (independent) between the radio transmitter and receiver allows for manual control and arming/disarming of the aircraft.

The Robot Operating System (ROS) is what facilitates the majority of inter-component communication over the WiFi network. ROS is a Linux middle-ware and development protocol for creating modular programs for robotics. ROS allows for real-time communication between machines running individual nodes, or executables, over a WiFi network. In our system, all subsystems communicating via ROS either are or will be developed as ROS nodes to be run on a machine with Linux installed. For more information about ROS nodes and how they communicate over a network, see http://www.ros.org/.

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UAS Subsystem Testing

ID	Rev.	Date	Description	Author	Checked By
SS-002	0.1	10-29-2018	initial draft	Andrew Torgesen	Derek Knowles
SS-002	1.0	10-31-2018	pre-design review revisions	Andrew Torgesen	Tyler Miller
SS-002	1.1	11-08-2018	after design review revisions	Kameron Eves	Jacob Willis

1 Introduction

As described in the UAS Subsystem Interface Definition document (SS-001), there are two main data links between the aircraft and the subsystems on the ground during a competition flight:

- The **900 MHz Radio Link** between the RC transmitter and receiver constitutes the minimal level of communication necessary for flight. The RC link allows a safety pilot to arm/disarm the aircraft's throttle and toggle the autopilot. As stipulated in our key success measures, we are trying to minimize instances when the safety pilot must manually take over the aircraft via the RC link. The ideal flight would not utilize this communication method. However, the RC link is necessary for safe operation and as such is essential to our product. If RC is lost, then the autopilot should immediately activate a *failsafe* mode.
- The **Ubiquiti WiFi Link** between the Ubiquiti Rocket (on the ground) and Bullet (on the aircraft) allows for the exchanging of data over a ROS network. Effectively, the Rocket and the Bullet allow for network connectivity between all subsystems on the ground and in the air. For example, within our key success measures, target characteristics identified pre-requires the ability to communicate images with the ground station. The aircraft's proximity to waypoints and obstacles are also reported through this data link. Thus the Ubiquiti WiFi link will be essential to a successful performance in our key success measures.

Almost all subsystem interfaces and performance measures depend on these two data links. Outlined in this document are testing procedures and results to evaluate the quality and reliability of each of these vital data links for the UAS system as a whole.

2 Testing Descriptions and Procedures

Table 1 outlines key characteristics of the WiFi and RC data links that should be tested, as well as how they should be tested.

Table 1: Description of testing procedures for UAS WiFi and RC data links.

Test name	Characteristic being tested	Procedure
RC failsafe	If RC connection is lost, then the flight control software should execute a failsafe mode to avoid an uncontrolled crash.	While the aircraft's autopilot is active, kill the RC transmitter. Observe what the autopilot does. It should guide the aircraft into a loiter flight.

Network loss	If the network connection between the aircraft and the ground is lost, then the aircraft should still be able to complete the tasks allocated to it until connectivity is regained.	While the aircraft is flying a mission, point the Ubiquity Rocket away from the aircraft, killing the ground-to-air WiFi connection. There should be no visible deviation of the aircraft from its current mission, and RC the connection should still be active.
Network reliability	The network should be able to connect upon boot-up of all subsystem components. Connection should be robust to external conditions and allow for a satisfactory data transfer rate.	In an outdoor environment, turn on all subsystem components and ensure that they all connect to the network automatically. Max out the stream rate of the camera to the onboard computer. Activate all subsystems that communicate over the network, and measure data transfer rates–particularly the following: • Images should be able to stream over the network at a rate of ≥ 1 Hz. • UAS state data should be viewable on the ground station machines at a rate of ≥ 4 Hz. • JSON data packets should be able to be sent to the interop server at a rate of ≥ 4 Hz.

ROS failure	If the ROS network fails, then the autopilot can no longer fly the aircraft. The safety pilot should be able to take back control of the aircraft over RC to guide it to safety.	While the autopilot is running, kill the ROS network on the aircraft's on-board computer with ssh. RC connectivity should still be active, and the safety pilot should theoretically be able to control the aircraft well enough to either recover the vehicle or prevent causing harm to surroundings as it crashes.

3 Testing Results

Table 2 gives the results of testing according to the procedures outlined in Table 1, as well as conclusions drawn from those results.

Table 2: Test results for the evaluation of the UAS WiFi and RC data links.

Test name	Test results	Conclusions
RC failsafe	After RC is lost for $\approx 30s$, the autopilot triggers a "return to land" protocol, landing near where it took off from.	The RC failsafe mechanism built into the autopilot has been found to be in line with the AUVSI competition rules.
Network loss	Loss of connection between the Ubiquiti Rocket and Bullet has no discernible impact on the autopilot–the only consequence is that the groundstation computers are unable to view the states of the aircraft over the ROS network. Communication resumes once the aircraft is back in range of the Rocket.	• It will be beneficial to have an on-board state recorder to record all ROS messages for later viewing, even if connection to the aircraft is lost temporarily. • We need to run tests to measure the range of the Rocket/Bullet connection when the Rocket is pointed directly toward the aircraft during flight.

Network reliability	Over the course of numerous flight tests, the network connection starts up reliably in all cases but one. There is a particular spot in a field in Springville where the network will never connect. Moving one block over, the network always connects. • *Image stream rate:* 3-4 Hz • *State stream rate:* 40-45 Hz • *JSON stream rate:* 3-4 Hz	• The network streaming rate has been found to be adequate. It is possible that we will want to purchase a more powerful router to allow for faster streaming rates at longer distances. • We have only run the network speed test with the aircraft on the ground; it would be nice to run another speed test in conjunction with a test of the maximum range of the Ubiquiti network connection. • The instance of never being able to connect in a particular geographical location is troubling. This quirk merits further investigation.
ROS failure	The RC connection to the aircraft has been found to be reliable and capable of manual takeover in any situation, as long as the batteries of the transmitter are not depleted. It has been found that certain settings should be toggled on the transmitter to conserve power, otherwise it experiences a battery life of about half an hour, which is inadequate.	• The range of the RC connection has been found to be adequate within a radius of $\approx 300ft$. • We should run an additional test to determine the approximate maximum range of the RC connection.

4 Conclusion

Based on the results documented in Table 2, we have determined that **our chosen principal inter-component data links are adequate for the competition environment and will not inhibit excellent performance in our key success measures**. Further tests are required to determine the boundary conditions (such as maximum possible distance) of their functional use.

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Airframe Subsystem Requirements Matrix

ID	Rev.	Date	Description	Author	Checked By
AF-001	0.1	10-23-18	Initial Draft	Tyler Critchfield & Ryan Anderson	Derek Knowles
AF-001	0.2	11-06-18	Revisions for Final Submission	Tyler Critchfield	Ryan Anderson & Kameron Eves

Product: UAS
Subsystem: Airframe

Upper Acceptable	Ideal	Lower Acceptable	8 Looks decent	7 Fast and cheap rebuild	6 Capable of carrying UGV and water bottle	5 Complies with AMA safety code	4 Components are protected	3 Minimize flight path deviation	2 Capable of traveling an extended distance	1 Capable of flight for extended period of time	Market Requirements	Performance Measures	Units
			1	3	3	9	9	9	9	9	Importance		
N/A	75	40							●	●	1	Battery life	Minutes
N/A	20	5			●				●	●	2	Lift-to-drag ratio	Unitless
1	1	0.2			●				●	●	3	Motor/prop efficiency	Unitless
50	4	0			●				●	●	4	Airframe weight	Kilograms
30	15	10			●				●		5	Average flight speed	Meters/second
20	10	N/A			●			●			6	Stall speed	Meters/second
-0.01	-0.05	-0.1						●			7	Spiral stability eigenvalue	Unitless
0.2	0.1	0						●			8	Static margin	Unitless
0.15	0.1	0.05						●			9	Cn,beta (yaw)	Unitless
0	-0.1	-0.15						●			10	Cl,beta (roll)	Unitless
0	0	0					●				11	Number of components that fall off the plane	Unitless
0	0	0		●			●				12	Number of damaged components on landing	Unitless
0	0	0				●					13	Number of AMA safety code violations	Unitless
1	0.5	0.4			●						14	Lift coefficient	Unitless
12000	10000	8000			●						15	Storage volume	Cubic centimeters
4	0	0		●							16	Time to rebuild	Hours
10	10	5		●							17	Focus group ease of repair	1-10 scale
10	10	5	●								18	Focus group coolness rating	1-10 scale

Figure 1: Airframe subsystem requirements matrix. Note that sometimes ideal values are unrealistic; rather, they are ideal. E.g., the ideal required build time is not time at all. Realism will be incorporated into target values in a future version of the Requirements Matrix.

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Airframe Subsystem Concept Selection Matrix

ID	Rev.	Date	Description	Author	Checked By
AF-003	1.0	10-31-2018	Concept development initial stage	Ryan Anderson	Andrew Torgesen
AF-003	1.1	11-06-2018	Concept development first revision	Ryan Anderson	Tyler Critchfield

1 Concept Selection Metrics

In general, metrics used in concept selection of the airframe were inspired by the Airframe System Requirements Matrix. These were in turn inspired by the generalized System Requirements and our Key Success Measures. Based on these documents, it was determined that one of the most important requirements for the concept is its build time. This is in light of a crash shortly before last year's competition that required a radical design change. Since not enough time was available to rebuild the original design, last year's team purchased an airframe. In order to prevent such an accident from recurring, we hope to optimize build time. As a second consideration, any change in airframe design will require some adjustment to our controls algorithm. Consequently, the estimated time needed for controls adaptation is another metric for our concept selection matrix.

Additionally, the two parts of the competition with the most room for improvement over last year's performance are object detection and payload delivery. A slower flight speed with greater stability would allow for sharper image capture as well as a less-complicated payload drop. In order to measure this, it was determined that wing area, airframe weight, wing area-to-weight ratio, and stability would be valuable metrics for selecting a concept that would maximize our performance in these competition tasks.

Other more obvious requirements for the airframe include sufficient volume capacity for components and payload, sufficient range to carry out the mission, and low enough cost to remain in budget. These were also included as concept selection metrics.

2 Metric Scoring

Concept selection metrics were evaluated by comparing their estimated outcomes to the airframe used in last year's competition (Table 1). Where possible, quantitative specifications were obtained online for metrics such as wing loading, wing area, weight, cost, and volume capacity. Range was measured primarily to show distinction between fixed wing and copter concepts. Other metrics were evaluated more qualitatively, as in the estimated difficulty for controls implementation and stability. Weights were chosen with reference to our key success measures. Metrics with a greater effect on our key success measures were given higher weights.

3 Concept Selection Idea Descriptions

3.1 My Twin Dream (MTD)($170)

Last year's airframe used the MTD design as a last minute replacement for their custom airframe that crashed. As shown in Figure 1, MTD is a twin propulsion fixed wing aircraft.

Table 1: Concept Selection Matrix for the airframe. Metrics for each concept are multiplied by their respective Metric Weight and summed to provide an overall comparison rating.

Metric	Metric Weight	My Twin Dream	Nimbus Pro	Titan	Modified My Twin Dream	Modified Nimbus Pro	Custom Traditional Fixed Wing	Custom Flying Wing	Hexa copter
Wing Area	**2**	3	4	4	5	5	5	5	5
Weight	**2**	3	2	2	3	2	4	5	4
Wing Loading	**4**	3	4	4	5	5	5	5	5
Volume Capacity	**4**	3	4	5	3	4	4	1	5
Stability Control	**2**	3	3	2	3	4	4	2	5
Build Time	**5**	3	3	3	2	2	1	2	2
Monetary Cost	**1**	3	3	3	2	2	4	4	1
Range	**5**	3	3	3	3	3	3	3	1
Controls Implementation	**5**	3	3	2	3	3	2	1	1
Totals	**-**	**90**	**98**	**95**	**96**	**100**	**96**	**82**	**85**

It's made of a sturdy and durable foam, Expanded PolyOlefin (EPO) with a wingspan of 1.8 m, a length of 1.3 m, and weighs about a kilogram (without components). The MTD airframe performed fairly well for last year's team. It had the necessary stability, range, and endurance to complete the competition mission. Some disadvantages are that the plane flew too fast during the competition and didn't have enough room in the fuselage for the water bottle payload. The latter is especially relevant this year because our payload is now an unmanned ground vehicle (UGV). As an off-the-shelf product, MTD is fairly easy to assemble and rebuild if needed. It's durability also minimizes needed repair upon crashing. One reason time to rebuild is so vital to this project is that every other subsystem (controls, vision, network, UGV, etc.) is dependent on the airframe working and able to fly. MTD is already integrated with ROSPlane and would only need fine tuning of the controls at this point. We used this as the reference design in our concept selection matrix.

3.2 My Fly Dream Nimbus Pro ($190)

Similar to MTD, the Nimbus Pro from My Fly Dream (Figure 1) is also a twin propulsion fixed wing aircraft. Some advantages to this design include a larger wing span (1.95m) and a larger fuselage compartment. The larger wing span can help this plane fly at a slower velocity, although this advantage is offset slightly by a larger weight. The increased fuselage storage room will also give us a better chance of fitting our UGV payload. We estimate Nimbus Pro to be very similar to MTD in other metrics such as stability, time to assemble/rebuild, cost, range, and controls adaptation.

3.3 Skywalker Titan ($260)

The Skywalker Titan is another large fixed-wing airframe we would be able to purchase (Figure 1). Titan has the largest wing span and payload storage capacity of the three off-the-shelf options we are considering. A unique feature to this design is the V-tail in lieu of the traditional tail. This would be difficult and time consuming to adapt for in the controls because now the elevator and rudder control surfaces are combined. Adjusting these combined surfaces would affect the dynamics differently than would the traditional control surfaces. We have also heard through our sponsor, Dr. McLain, that one of his students would not recommend this plane because it is difficult to fly (even without autopilot enabled).

3.4 Modified My Twin Dream

One major disadvantage to off-the-shelf products is that they are designed for us; we have no control over optimizing certain design parameters to improve the airframe performance. Another design we considered is taking the same MTD plane we already have and using

Figure 1: Three commercially available airframes investigated. According to Dr. McLain, Skywalker Titan is incredibly unstable. Images taken from banggood.com.

custom wings that we would design. With this we would be able to improve performance (e.g. increasing wing area to fly slower) without using all our time on designing an entire airframe. Last year's team designed their own airframe, which took a lot of their time and ultimately resulted in a crash. This modified MTD design would maintain the same cost, controls adaptability, durability, and time required to assemble/rebuild as MTD. We would be able to design the wing to fit with the current MTD design and make multiple wings as backup in case of wing failure when crashing or landing. If the plane was damaged and we needed to adjust our design, the other subsystems would not need to wait any longer than they would for normal repairs for MTD. In the meantime, they could fly the plane with the normal MTD wings until we had the new wings designed and made. Another advantage of this idea is that it would give us more learning experience in airframe design than using MTD on its own.

3.5 Modified Nimbus Pro

This design is very similar to the Modified MTD (see above). We would have the durability, trusted flight dynamics, and fast time to rebuild as an off-the-shelf plane with the added benefit of the increased wing area (we can only replace part of the wing, so the original wing design is still impactful) and increased storage capacity for the UGV payload. We would also have some control over stability. This combination of benefits is why we have chosen this as our concept.

3.6 Custom Fixed Wing

Last year's team initially used a custom fixed wing design for their airframe. A custom design would give us more control over airframe weight and performance, which in turn would make the other mission areas easier to accomplish. This would also give us valuable learning experience in learning to optimize the design of all airframe components to maximize performance. However, as previously mentioned, this design comes with high risk and cost. While monetarily it may be cheaper to build, it uses up a lot more time of all team members: our most valuable resource. Last year's experience shows the risks associated with a custom design - a crash a few weeks prior to the competition made it so that the team had no time to rebuild the airframe. With their remaining time, they were able to get everything working with MTD, even when that plane crashed a couple days before the competition at the competition site. While the idea of a complete custom design is exciting and has the most potential for high performance, we are not ready to take the associated risks.

3.7 Custom Flying Wing

A flying wing design is an airframe without a tail or a fuselage. As the name implies, it is literally just a wing that flies. Some benefits to this design include efficiency and simplicity (there is no need to design a fuselage or a tail). The main benefit would be durability; a flying wing can withstand crashes very well. One disadvantage would be storage space. MTD didn't have enough room for the water bottle payload in last years' competition; a flying wing would have even less space to store our UGV payload. Another major disadvantage is time required to design and build the wing. A flying wing is trickier to design to ensure stability; without the correct design, it is easy to have a longitudinal pitching moment. This difficulty would necessitate multiple design iterations, which would use up more time. And as previously stated, more time spent on airframe design and construction is more time everyone else needs to wait to test their subsystems. It would also take more time to adapt ROSPlane, because the elevator and aileron control surfaces would be combined (with no rudder).

3.8 Hexacopter ($3,000-$6,000)

A hexacopter concept would provide significantly enhanced maneuverability and control to the UAS, as well as allowing us to drop the payload while stationary. It should have sufficient volume capacity for components and payload. However, since designs from the past few years have all used a fixed wing, changing to a copter design would require huge overhead in adapting the controls algorithm. Additionally, building our own copter would cost significantly more than a fixed wing, since 6 motors would be required at $200 a piece by first estimates. Purchasing a copter off the shelf is out of the question, since copters with the specifications we need cost upwards of $3,000. Additionally, since range requirements for the competition were increased this year, the limited of a copter concept is a significant disadvantage to a fixed wing concept.

4 Conclusion

The Modified Nimbus Pro was selected for our chosen concept as it scored highest on the selection matrix. Although it will require slightly more time to build, we believe that the increase in performance justifies the time expense. The concept and how it responds to our Key Success Measures are described in greater detail in the Airframe Concept Description.

Brigham Young University

AUVSI Capstone Team (Team 45)

Airframe Concept Description

ID	Rev.	Date	Description	Author	Checked By
AF-002	0.1	10-31-18	Initial Draft	Tyler Critchfield	Ryan Anderson
AF-002	1.0	11-06-18	Revisions for Final Submission	Tyler Critchfield	Ryan Anderson

1 Introduction

This artifact describes our chosen airframe concept and how it relates to the Key Success Measures artifact.

2 Concept Description

We selected the modified Nimbus Pro for the Airframe subsystem. This airframe modifies a traditional twin propulsion fixed wing RC airframe (see Figure 1) that can be purchased off the shelf. The original RC airframe has a wing span of 1.95 m, a wing area of 5700 cm^2, a fuselage length of 1.29 m, a payload storage volume of about 8000 cm^3, and an empty weight of 1.9 kg. In this design, about two-thirds of the wings are able to be disconnected for easy storage and transport (see Figure 2). We could use this to our advantage by creating new wing extensions to attach to the plane instead of the original wings. These wing extensions would likely have a longer span, but would be restricted to the existing design in root airfoil shape and root chord length. We would have freedom to adjust span, taper ratio, tip twist, and tip airfoil if we so choose. We would model these design parameters in XFLR5 to determine the best wing extension design. The wing extensions would be made of foam and easily constructed using the foam cutter in EB 112.

The modular nature of these adjustments would make it easy to assemble and rebuild if necessary, especially if redundant parts are purchased and created. The lack of a modular, easily rebuild-able design was almost detrimental to last year's team when a crash shortly before the competition forced them to completely re-design their airframe. We hope to avoid that problem this year by implementing a modular design. To be successful, vision, controls, and UGV subsystem teams will need to prototype and test their designs often, but no one can truly test their designs without an airframe that flies. Having a modular wing design would still allow for fast rebuild, ensuring that other team members would not be wasting time waiting for the airframe to be rebuilt. In the case that a redesign is necessary, the other subsystem teams can use the off-the-shelf wings for the Nimbus Pro while waiting. Also, in the case that we find other design activities that take precedence over redesigning the wings, the original Nimbus Pro design will theoretically still work without modifications, albeit not as well. This provides flexibility in how we allocate our time.

3 Key Success Measures

This airframe concept was selected to optimize the achievement of the key success measures, which in turn will help us maximize our competition performance. First, we needed an airframe that could fly at a slower velocity. A slower velocity will increase maneuverability, making it easier for the autopilot to plan and execute a flight path that minimizes obstacles hit and improves waypoint proximity—two of our key success measures. In addition, a slower velocity will improve the image quality of our camera, which will theoretically increase the percentage of object characteristics identified. A slower velocity will also help airdrop accuracy.

Second, we needed an airframe with sufficient storage capacity to carry the payload. Since this year's competition requires us to drop a UGV (Unmanned Ground Vehicle) in addition to a water bottle, sufficient fuselage volume is desirable. Payload storage capacity will prevent us from needing to mount the payload to the airframe exterior. Keeping the payload inside the airframe will prevent excess drag and allow the plane to fly at a slower velocity, assisting all of the key success measures already mentioned.

Third, the time to build the airframe was another measure we used in concept selection that indirectly affects all of the key success measures. If the airframe takes too long to build, it is difficult for us to test our other subsystems that are directly working on those key success measures (e.g. imaging subsystem needing to test identified characteristics).

Figure 1: The Nimbus Pro from My Fly Dream. Image taken from banggood.com.

4 Conclusion

In short, the selected concept was chosen to optimize our key success measures. We are confident the Modified Nimbus Pro concept will help us maximize our performance in competition.

Figure 2: This is where the wing disassembles and where we would attach our custom wings. This is a photo of My Twin Dream, but this concept is the same for the Nimbus Pro.

Brigham Young University

AUVSI Capstone Team (Team 45)

Unmanned Ground Vehicle Initial Concept Development

ID	Rev.	Date	Description	Author	Checked By
GV-001	0.1	2018-10-23	Initial Draft	John Akagi	Jacob Willis
GV-001	1.0	2018-10-31	Added introduction	Jacob Willis	Andrew Torgesen
GV-001	1.1	2018-11-8	Added conclusion and reference key success measures	Jacob Willis	John Akagi

1 Introduction

This document describes the initial concept generation of the Unmanned Ground Vehicle system.

2 System Objective

In the 2019 AUVSI SUAS competion, points are awarded for successfully delivering an Unmanned Ground Vehicle (UGV) to a target location; additional points are awarded if the vehicle drives to another target location. The UGV must be capable of carrying an 8oz water bottle, and the impact must subjectively be "soft." During the delivery the airframe cannot drop below 100ft ASL, so a system or mechanism for landing the UGV without damage is required.

Because points can be received for just delivering the UGV without it driving, and because the payload drop problem is the most challenging part of the UGV design, the key success measure related to this subsystem is airdrop accuracy. With this in mind, determining how to accomplish the payload drop is the subject of this concept development. The UGV is assumed to be a 700 gram "black box" capable of driving to its target once it is on the ground.

3 UGV Delivery Initial Concepts

The UGV delivery concepts were generated individually by team members and then discussed as a team to combine similar ideas. After all ideas were discussed, a subset were selected as being most promising and advanced to the testing stage. The concepts generated and initial decisions are listed in Table 1. Additionally, the concepts are shown as a concept classification tree in Figure 1 to highlight the variety of ideas generated.

Table 1: Description of initial ideas and decisions made. "Discarded" indicates the idea was considered unfeasible, "Investigate" indicates the idea was studied further, "Modify" indicates the idea was considered usable in conjunction with another idea or ideas.

Idea	Description	Decision	Rationale
Skycrane	UGV is lowered on a rope from the UAV	Investigate	Would eliminate the need for most cushioning and control surfaces on the UGV
Fins	Fins are used to give minimal control to a fast falling UGV	Investigate	Would be smaller than full glider wings but still allow decent control

Glider	Unpowered aircraft is used to control the falling UGV	Investigate	Would likely provide the greatest amount to control
Parasail	A controllable parachute is used to steer the UGV	Discarded	Difficult and unknown controls
Control Grids	Similar to SpaceX, grids are used to steer the descent of the UGV	Discarded	Too complex for this application
Magnus Effect	Spin the wheels of the UGV in the air to generate lift and control UGV attitude	Modify	Could be used in conjunction with other methods but unlikely to have much effect by itself
Autogyro	Unpowered helicopter rotors are used to slow descent and blades can be tilted to control the drop	Discarded	Mechanism was considered too complex
Bounce	UGV uses some elastic material under it to decrease the time of impact	Discarded	Bouncing would likely not reduce the impact forces to survivable levels
Airbag	An airbag is inflated just before lading to cushion the drop	Discarded	Needs precise measurements to determine when to inflate airbag, Airbag inflation mechanism is likely to require dangerous materials
Springs	Springs are placed under the UGV to absorb the energy from the drop	Modify	Could be used to reduce impact energy but unlikely to be able to dissipate all by itself
Counterweight	A large mass is ejected downwards just before impact in order to slow UGV descent	Discarded	Requires ejecting a large mass at high acceleration which is likely to be dangerous and impractical
Crumple Zone	Use a deformable material to break and absorb energy when UGV impacts ground	Modify	Could be used to reduce impact energy but unlikely to be able to dissipate all by itself
Balloons	Use balloons to increase drag and provide some lift	Discarded	Would be large and impractical to carry on board the UAV
Parachute	Use a parachute to slow the descent of the UGV	Investigate	Simplest idea and almost guaranteed to work

Seedpod	Attach a single propeller blade to the UGV which would cause the UGV to spin and slow its descent similar to how maple seeds work	Discarded	The UGV is likely too heavy to implement this properly
Nothing	Make the UGV as rugged as possible and drop it from the UAV with no slowing mechanism	Discarded	Any UGV that is rugged enough to survive a 100 ft drop would be too heavy and bulky to carry on the UAV
Low Drop	Drop below the minimum allowable flight level and drop the UGV from a lower altitude for increased survivability	Discarded	Would violate rules that state we must remain above a certain altitude

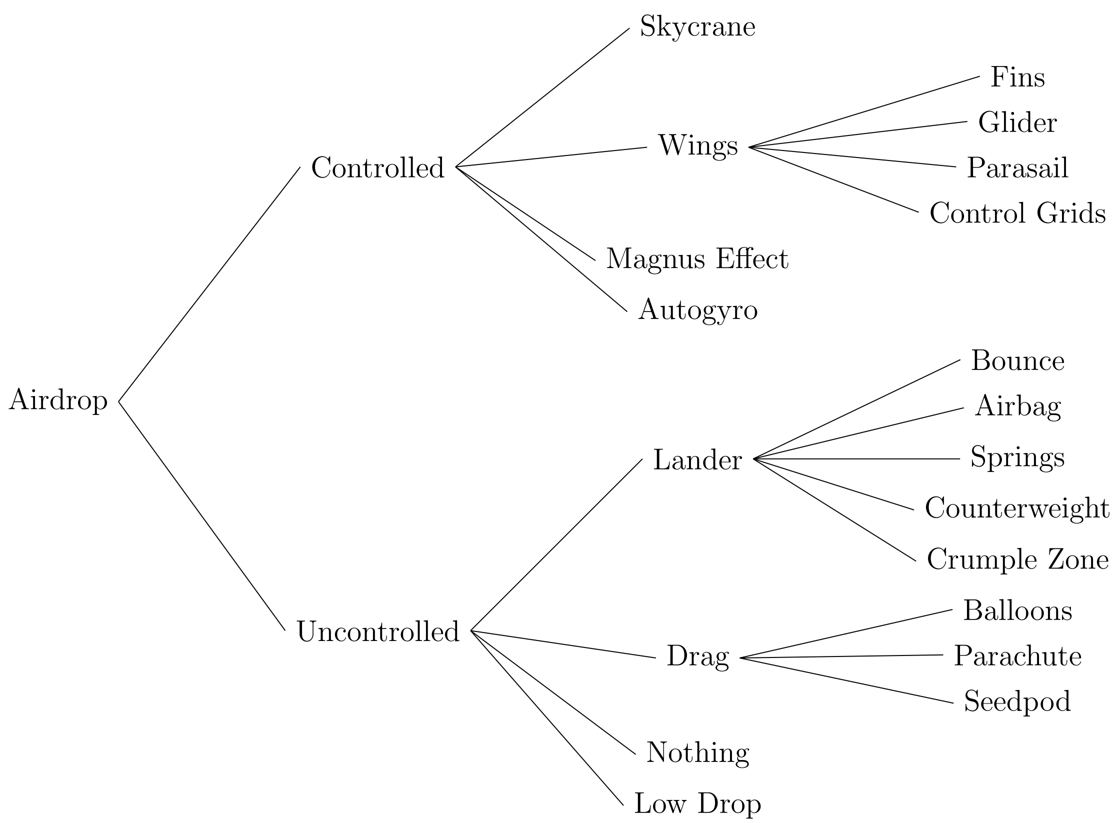

Figure 1: Concept development tree of the initial ideas generated for the payload delivery system.

4 Conclusion

Through our concept generation efforts, seventeen distinct concepts were created. After considering novelty and feasibility, four concepts were selected for additional investigation. These concepts are the skycrane, glider, and parachute, along with combining the parachute and fins concept to create a controlled parachute.

Brigham Young University

AUVSI Capstone Team (Team 45)

Unmanned Ground Vehicle Requirements Matrix

ID	Rev.	Date	Description	Author	Checked By
RM-001	0.1	10-23-2018	Initial requirements	Jacob Willis	Brady Moon
RM-001	1.1	10-26-2018	Better performance measures	Jacob Willis	Kameron Eves
RM-001	1.2	10-26-2018	Edits after design review	Brady Moon & John Akagi	Kameron Eves

Product: UAV
Subsystem: PAYLOAD/Unmanned Ground Vehicle (UGV)

Notes:
*normalized by the fusalage diameter cubed

			1	2	3	4	5	6	7
	Subsystem Performance Measures		Drop mechanism mass	Weight mechanism can support	Aircraft internal volume consumed*	Stowed drop mechanism drag	Maximum landing velocity	UGV landing distance from target	Rule violations
	Units		kg	N	%	N	m/s	m	cnt
	Target Design Requirements	**Importance**	1	2	3	4	5	6	7
1	Complies with competition rules	5	●						●
2	Capable of lowering the payload to the ground	5	●	●					
3	Lands UGV within landing zone	3					●	●	
5	Delivers UGV without damage	3		●			●		●
6	Deployable from airframe	4			●	●			
7	Does not interfere with takeoff/landing	3	●			●			
8	Causes minimal aerodynamic interference	3				●			
9	Drop mechanism does not interfere with UGV movement	2					●	●	
		Lower Acceptable	0	0.6	-	0	0	-	-
		Ideal	0.1	1.3	0	0.3	1	0	0
		Upper Acceptable	0.6	-	50	1.5	5	22	1

Figure 1: Requirements matrix for the subsystem which will deliver the UGV to the ground.

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AUVSI CAPSTONE TEAM (TEAM 45)

Unmanned Ground Vehicle Delivery Concept Selection

ID	Rev.	Date	Description	Author	Checked By
GV-002	1.0	10-31-2018	Created document and decision matrix	Jacob Willis	Andrew Torgesen
GV-002	1.1	11-6-2018	Document revised with comments from design review	John Akagi	Andrew Torgesen and Ryan Anderson

1 Introduction

This document captures our decision making process for selecting between our four primary UGV drop concepts. Each of the primary concepts is described in further detail below.

1.1 Parachute

A parachute is attached to the UGV, and is opened upon release of the UGV from the aircraft. To improve the accuracy of this concept, the effect of wind on the parachute and payload is characterized and used to calculate the optimal drop location given the estimated wind speed at the time of drop. No control mechanisms are used during the drop. For concept verification purposes, the parachute is dropped from a height of 35 ft with no wind to test if the accuracy and impact speed are within the acceptable limits.

1.2 Parachute with Controls

Similar to the parachute concept, but control surfaces (fins) are attached to the payload and actuated as the payload drops. This provides some controlability to stabilize the drop and to improve accuracy. For concept verification purposes, the parachute is dropped from a height of 35 ft with no wind to test if the accuracy and impact speed are within the acceptable limits.

1.3 Skycrane

The UGV is lowered on a string or rope while the airframe circles overhead. The circling motion causes the UGV to orbit in a smaller circle as it is lowered. When the UGV hits the ground, it releases itself from the string to prevent interrupting the flight of the airframe. Preferably the UGV controls the rate of descent so it can easily feed back its distance from the ground. Potential winches that could be used to lower the payload were found online and their characteristics were used to check compliance with the needed guidelines. We were unable to devise tests to determine landing velocity and precision since these measures are highly reliant on the control of the airframe. However, we did discuss with Dr. McLain, who has had experience with tethered payloads, to determine the relative performance of the skycrane option.

1.4 Glider

A glider is carried on board the airframe and is released when the UGV drop is attempted. The glider either incorporates or carries a ground vehicle. The glider is unpowered, but is controlled like a normal aircraft.

1.5 Reference: Un-aided drop

The UGV is dropped from the airplane without any mechanisms for slowing its descent. This is used as the reference for the other concepts. Because the competition rules require a gentle landing, an un-aided drop cannot be used as the selected concept. Using the equation for terminal velocity, $V_t = \sqrt{\frac{2mg}{\rho A C_d}}$, with values of surface area $A = .0225m^2$, coefficient of drag $C_d = 1.05$ (coefficient of drag for a cube), air density $\rho = 1.225kg/m^3$, and mass $m = .711kg$ (mass of payload used to test parachute concepts) gives a estimated terminal velocity of 22.0 m/s. Compared to the estimated speeds of the parachutes which ranged from 2.7 m/s to 4.8 m/s, 22.0 m/s is certainly a hard landing. This was additionally confirmed when we dropped the payload from a height of 35 ft without a parachute and one of the water bottles broke on impact.

2 Decision

To make an informed decision, each of the primary concepts was evaluated according to the methods described in GV-003 and GV-004. Due to constraints on time and resources, some concepts were evaluated using a model rather than a prototype. The concepts were scored on a 1-5 scale, and the results are captured in Table 1.

Table 1: A decision matrix for the UGV Drop Method. A scale of 1-5 was used for weights with 5 having high importance and 1 having low importance. Because no points are awarded if the UGV is damaged or does not land "softly" (this is determined subjectively by the judges), a weight of 10 was applied to the max landing velocity. A 1-5 scale was used to rate each option's performance under each requirement. In this case, a 1 was used to indicate poor performance while a 5 indicates favorable performance.

UGV Drop Method	Weight	Glider	Sky Crane	Parachute	Parachute with controls	Un-aided Drop (Reference)
Drop Mechanism Mass	3	4	2	5	5	5
Weight mechanism can support	3	2	5	4	4	5
Aircraft internal volume consumed	4	4	2	3	3	4
Stowed drop mechanism drag	5	1	4	4	4	5
Max landing velocity	10	2	5	4	4	1
UGV landing distance from target	5	2	3	4	5	5
Development complexity	5	1	1	4	2	5
Totals	-	74	119	139	134	131

3 Conclusion

As can be seen from the decision matrix in Table 1, the parachute concept scored the highest. Other high-scoring concepts included the parachute with controls, which was slightly more accurate but has much worse development complexity. The unaided drop is extremely simple and actually most accurate, but is unacceptable since it would be very difficult to construct a UGV capable of surviving the drop, let alone achieve a soft landing as required by the competition rules. The parachute will allow us the best chance of meeting our key success measure of 25ft drop accuracy. This concept is described in more detail in GV-005.

Brigham Young University

AUVSI Capstone Team (Team 45)

Unmanned Ground Vehicle (UGV) Parachute and Glider Testing Description

ID	Rev.	Date	Description	Author	Checked By
GV-003	0.1	2018-10-30	Initial Draft	John Akagi	Kameron Eves
GV-003	1.0	2018-11-6	Revised after design review	John Akagi	Andrew Torgesen
GV-003	1.1	2018-11-8	Added Intro and Conclusion	Brady Moon	John Akagi
GV-003	1.2	2018-11-9	Added Glider Test procedures	Tyler Critchfield	Ryan Anderson

1 Introduction

This artifact details the methods and results of testing parachute UGV drop system concepts from GV-001.

2 Parachute Testing

The parachute concepts were tested in the high bay in the Engineering Research Lab. There is scaffolding that allowed us an approximately 35 foot drop into a 20 foot by 10 foot area. Initial testing was done on the methods to measure the landing velocity of the payload and to get a basic understanding of what variables were important to control. After the initial testing, we decided to test a large parachute, a small parachute, and a small parachute with control fins on the payload because these seemed to have the largest impact on the precision of the drop and the landing speed. The large parachute was 48 inches in diameter with a 16 inch diameter spill hole. The small parachute was 30 inches in diameter with a 6 inch diameter spill hole. The fin design was comprised of two fins with a total surface area of 19.5 in^2.

We tested these three methods by dropping each one three times and recording the impact point to evaluate how well the drop system met the key success measure of airdrop accuracy. The payload weight for each drop was .711 kg. During these drops, we controlled the position, shape, and orientation of the parachute to reduce any effects that would be caused by imperfections in the construction of our parachute. For the drop with the fins, the fins were both oriented at approximately a 45°angle relative to vertical and turned to the right to try and offset the leftward drift of the small parachute. The parachute and setup for the parachute connections are shown in Figure 1. The results of the test are shown in Table 1 and the drop locations are shown in Figure 2.

For each drop, the parachute was held on two opposite side in a way to try and equalize the tension in each of the parachute cords. The payload was allowed to hang freely beneath the parachute, although the parachute was not released until any twisting motion of the payload had been damped out. Each payload was released from approximately the same place which was determined by visually lining the payload up with a target placed on the ground. The parachute was released into still air and the position of the initial impact was recorded by an observer on the ground. If the payload impacted the wall before reaching the ground, the observer would extrapolate the ground impact location by estimating the lateral speed and height of impact. The average initial impact position and the standard deviation of the spread were calculated.

Since we could only drop from a height of about 35 ft, the average impact position and standard deviation were calculated for a 100 ft drop using a simple linear extrapolation. We assumed that the payload would drift approximately 3 times as far in a 100 ft drop as it would in a 35 ft drop, multiplied the landing distances by that factor, and recalculated the standard deviation. While the actual payload drop will likely be less accurate due to cross winds and being dropped with an initial lateral velocity, these tests are useful in determining the relative accuracy of various delivery systems in ideal conditions. Additionally, based on our observations during the tests, we concluded that the parachutes were fully inflated and were at or close to terminal velocity when they reached the ground.

The landing speed was estimated by filming the impact of the payload and comparing the change in position of the payload between frames to a known measurement that was visible in the camera frame. The estimated velocities are reported in Table 2. As stated before, our subjective observations lead us to believe that the payloads were at terminal velocity when they hit the ground and so there will be little change in impact velocity between these tests and dropping the payloads from 100 ft. Although the smaller parachute has a velocity about twice the velocity of the large parachute, we did not feel that any of these hits would cause the destruction of the water bottle or UGV. Additionally, we feel that the appropriate addition of shock absorbers, crumple zones, padding, or other dampers would further increase the survivability of the UGV.

Table 1: The results of dropping the three different parachute systems. The average distance is the average lateral distance between the dropping and landing positions. The standard deviation is the standard deviation between all three drops for each system. The scaled standard deviation is the estimated standard deviation when payloads are dropped from 100 ft.

Method	Average Distance	Std. Deviation	Scaled Std. Dev.
Large Parachute	9.01 ft	0.95 ft	2.85 ft
Small Parachute	7.20 ft	1.38 ft	4.14 ft
Small Parachute with Fins	4.70 ft	1.08 ft	3.23 ft

Table 2: Estimated landing velocities of the parachute concepts. Landing speeds were calculated by filming the impact and comparing the change of position in the bottle between frames. These distances were then compared to a known measurement that was also in the video frame.

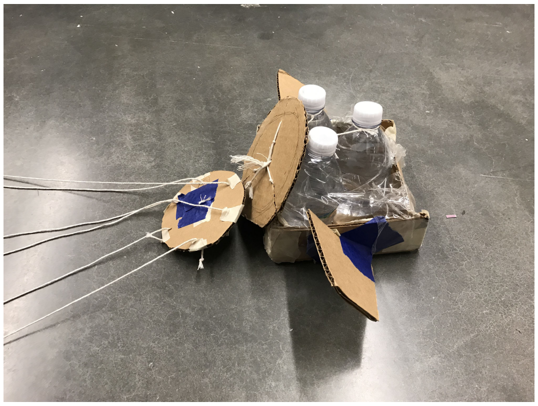
Method	Impact Velocity
Large Parachute	2.7 m/s
Small Parachute	4.8 m/s
Small Parachute with Fins	4.8 m/s

3 Glider Testing

A rough prototype was constructed based on a simple glider design in XFLR5 that was designed to carry a payload of 1 kg (see Figure 3). The prototype had a span of about

1 m and a mean aerodynamic chord of 10 cm. In testing we taped a small water bottle to the underside of the glider and dropped it 10 times from heights of 5 ft, 6 ft, and 7 ft, respectively. The horizontal glide distance was recorded. The standard deviation was calculated and then extrapolated to a drop height of 100 ft. These results are summarized in the artifact GV-004 UGV Drop Mechanism Concept Test Procedures and Results. Unfortunately, the prototype did not have sufficient lift with the designed weight attached; it simply fell without gliding. We assume this is because we were not testing it at its design velocity, and understand that this test was not very realistic. However, it did have adequate consistency with a small payload. This proves that with more design and better test procedures, the glider could perform well.

(a) Full configuration for parachute and fins.



(b) Control fins and connections to parachute.

Figure 1: Testing setup for the small parachute and fins option. The small parachute only method was the same but without the cardboard holder around the water bottles. The large parachute method was identical to the small parachute method but simply larger.

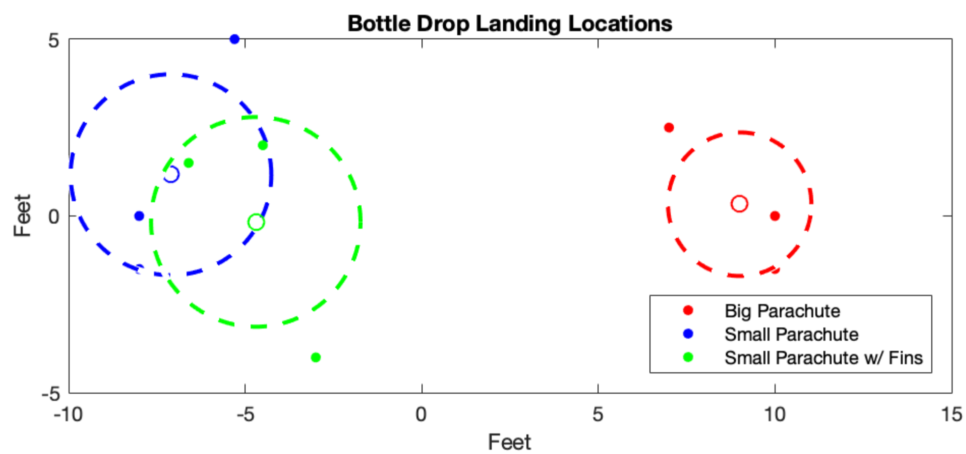
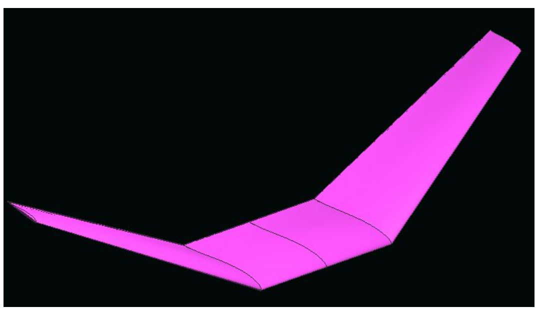


Figure 2: The location of the initial impacts of each of the drops as shown by filled in circles. Due to the constrained area of our testing location, some landing locations were extrapolated since they hit the walls before the ground. The open circles are the average location of impact. The dashed lines indicate the mean distance away from the average impact location. The colors differentiate between system types as shown in the legend.

4 Conclusion

Parachute drop concepts were tested in the Engineering Research Lab high bay for landing velocity and precision. Test results are used in artifact GV-004 for overall comparison of our concepts.



(a) *Simple prototype model simulated in XFLR5.*

(b) *Constructed glider prototype.*

Figure 3: Testing setup for the glider concept. A simple model was built in XFLR5. This was then built by using the foam cutter to cut out each of the 3 sections. These sections were glued together with a spar in the middle section. A water bottle payload was taped underneath.

Brigham Young University
AUVSI Capstone Team (Team 45)

Unmanned Ground Vehicle Drop Mechanism Concept Test Procedures and Results

ID	Rev.	Date	Description	Author	Checked By
GV-004	0.1	10-26-2018	Initial creation procedures listed	Jacob Willis	Andrew Torgesen
GV-004	1.0	11-6-2018	Additional detail added based on design review	John Akagi	Andrew Torgesen

1 Introduction

This document describes the procedures used to test each of the Unmanned Ground Vehicle (UGV) payload delivery concepts. Some of the tests were unnecessary for selecting between concepts, so they will not be performed unless required by subsystem engineering.

2 Test Procedures and Results

2.1 Drop Mechanism Mass

The mass of all components related to landing the UGV safely were determined and summed for each concept. Results are found in Table 1.

Table 1: Estimated total mass for the delivery system for the UGV.

Concept	Result
Parachute	.026 kg
Parachute w/ control	.124 kg
Skycrane	.160 kg
Glider	.08 kg

2.2 Maximum Deliverable Weight

In order to determine the maximum weight the concepts could deliver, the weight constraints of the individual components were determined. The maximum weight is the minimum load ratings. Results are found in Table 2.

Table 2: Maximum weight the concept can safely deliver. Weight determined by load ratings of components.

Concept	Result
Parachute	4 kg
Parachute w/ control	4 kg
Skycrane	3 kg
Glider	1 kg

2.3 Drop Mechanism Volume

The volume of all of the UGV drop mechanisms, and the volume needed for the UGV if the mechanism requires it be inside the aircraft is measured. Results are found in Table 3.

Table 3: *Volume required for each drop mechanism.*

Concept	Result
Parachute	462 cm^3
Parachute w/ control	462 cm^3
Skycrane	92 cm^3
Glider	864 cm^3

2.4 Stowed Drop Mechanism Drag

A preliminary estimate of this is made using the area of the mechanism that is exposed outside of the airframe and computing drag with $D = \frac{1}{2}\rho v^2 C_d A$ where air density $\rho = 1.225 kg/m^3$, velocity $v = 15 m/s$ is the estimated aircraft flight speed, area A is the cross sectional area of the drop mechanism, and C_d is the estimated coefficient of drag based on cross sectional area and standard drag coefficient tables. Results are found in Table 4.

Table 4: Estimated drag of the drop mechanism.

Concept	Result
Parachute	.278 N
Parachute w/ control	.278 N
Skycrane	.315 N
Glider	.245 N

2.5 Maximum Landing Velocity

A preliminary estimate of this is made by calculating the landing velocity based on video data taken during the drop testing. The the payload was compared to a known measure placed behind the payload and the change in position over time was used to calculate the impact velocity. Results are found in Table 5.

Table 5: Estimated landing velocity of delivery system.

Concept	Result
Parachute (48 in)	2.7 m/s
Parachute (30 in)	4.8 m/s
Parachute w/ control	4.8 m/s
Skycrane	Not Tested
Glider	1.9 m/s

2.6 Delivery Precision

A preliminary estimate of this is made by dropping a representative load with the mechanism from a height of 35 feet. The distance between where the load lands and the target is scaled to a 100 foot drop height and the standard deviation of the spread is reported. The precision of the glider was tested by dropping it from heights of 5, 6, and 7 ft and the precision was scaled to 100 ft. For more detailed explanation of the test procedure, see GV-003 UGV Parachute Testing Description. Results are found in Table 6.

Table 6: Standard deviation of initial impact, scaled to a 100 ft drop.

Concept	Result
Parachute (48 in)	2.85 ft
Parachute (30 in)	4.14 ft
Parachute w/ control	3.23 ft
Skycrane	Not Tested
Glider	28 ft

2.7 Rule Violations

A checklist of the relevant rules is checked for the concept. The number of violations for the concept is summed. Results are found in Table 7.

2.7.1 UGV Rules Requirements

The following outline the rules which must be followed in order to achieve any points.

- Must carry 8 oz water bottle
- Must not fly below minimum altitude
- Must land gently and without damage (subjective measure)
- Max weight of 48 oz

Table 7: Number of rules violated by delivery system.

Concept	Result
Parachute	0
Parachute w/ control	0
Skycrane	0
Glider	1

2.8 Conclusion

The preceding test results are used to select the optimal concept in GV-002.

Brigham Young University

AUVSI Capstone Team (Team 45)

Unmanned Ground Vehicle Delivery System Selected Concept Description

ID	Rev.	Date	Description	Author	Checked By
GV-005	1.0	10-30-2018	Wrote concept description	Kameron Eves	Andrew Torgesen

Introduction

This document gives a more detailed description of the selected concept for the UGV delivery system. As can be seen from our selection matrix (GV-002) and test results (GV-004), the selected concept is a parachute with fins.

Description

The UGV will be loaded within the aircraft. Upon a command from the flight controller system, small hatch will open and the UGV will fall out. Strings will attach the UGV to a lightweight fabric parachute. The fabric parachute will be loaded onto the aircraft in a tube that will allow the UGV to pull it out of the aircraft as it falls. This will help stop the tangling that can come from a folded parachute. After exiting the aircraft the parachute will be opened by drag. The drag caused by the fabric will slow down the system enough to allow the UGV to survive impact without damage. A visual depiction of our chosen system can be seen in Fig. 1.

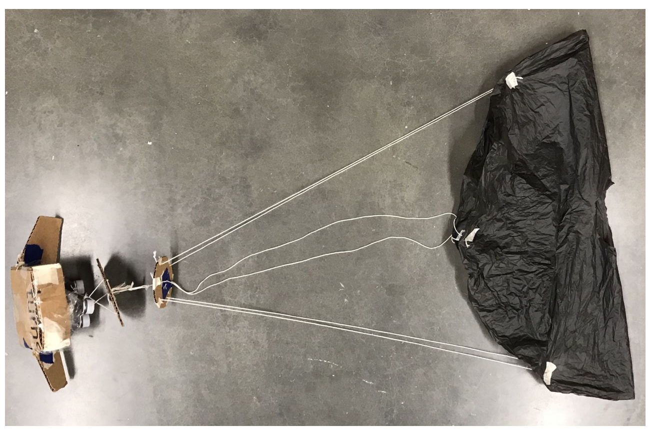


Figure 1: A simple prototype of our parachute as seen from the side.

An accurate landing is an important part of the competition. A hole in the top of the parachute will improve the accuracy of the system. As can be seen in Fig. 2 we tested this hole in our prototype. This hole is known in the industry as a spill hole because it allows the air to spill out of the center of the parachute. This does increase the velocity with which the system falls, but it also provides a market increase in the accuracy. This is because without the hole, the air become trapped within the system and excess air must move around the outside of the parachute as it falls. Imperfections in manufacturing and weather conditions mean that this this overflow around the outside of the parachute is always uneven. Thus the parachute is pushed to the side by the uneven overflow. This is analogous to pouring water into a cup. Once the cup is full, the excess water poured into it overflows over the side. A spill hole allows the overflow to "spill" out the top of the parachute in a way that won't affect the lateral velocity of the system. This is comparable to a small hole in the bottom of the analogous cup which allows the excess water to flow out the bottom of the cup instead of overflowing over the side.

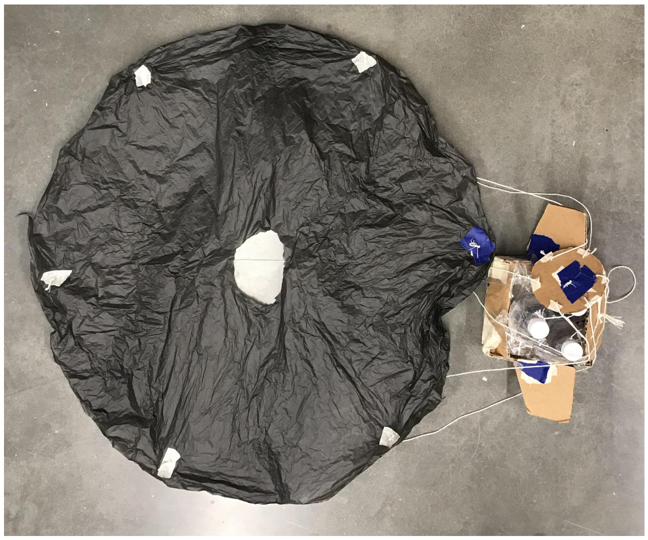


Figure 2: A simple prototype of our parachute seen from the top. Note the hole in the middle of the parachute. As mentioned above, we found that this greatly improved the accuracy of the parachute.

Fins are another way the accuracy of the system can be affected. These fins can be seen in our prototype in Fig. 3. As can be seen in our testing results artifact (GV-004) the fins did push the system one direction. This should allow us to slightly control our system as it falls. While this will not be enough to correct for large errors, it should be enough to ensure the system doesn't drift randomly. The protocol for dropping objects from a UGV, as detailed in *Small Unmanned Aircraft: Theory and Practice* by Randy Beard and Tim McLain, should also help improve our accuracy. This protocol uses the wind and velocity of the aircraft to predict the best location to release the payload.

Conclusion

Using the system described above, we are confidant in our ability to achieve a landing accuracy of within 25 feet. This is considered excellent performance in our key success measures and will give us 75% of the points possible in this portion of the competition.

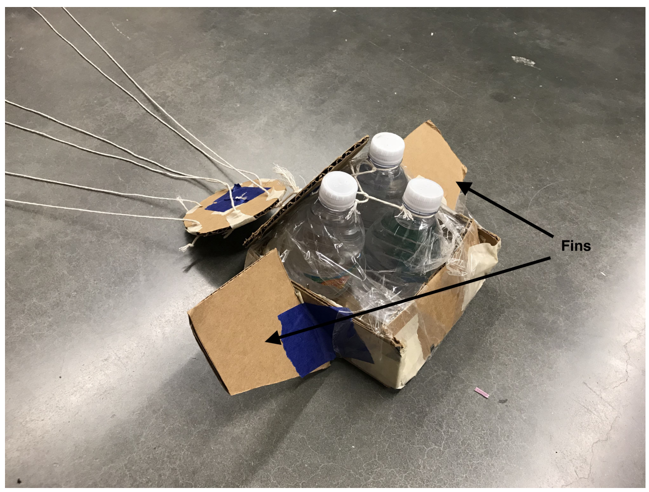


Figure 3: The payload we used to simulate the UGV. Note the fins. As mentioned above, preliminary results seem to indicate that these fins provided a small amount of control authority over the parachute's trajectory. This will help us improve accuracy

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Vision Subsystem Concept Selection Matrices

ID	Rev.	Date	Description	Author	Checked By
CS-002	1.0	10-24-2018	Initial release	Tyler Miller	Derek Knowles
CS-002	1.1	11-07-2018	Added table descriptions	Andrew Torgesen	Derek Knowles
CS-002	1.2	11-09-2018	Added intro & conclusion	Brandon McBride	Tyler Miller

1 Introduction

The concept selection matrices are used to aid us in our decision about which camera we should use in our imaging system. We compared 4 different cameras and weighed them against 7 requirements. Shown below are the matrices; one shows the rating we gave, and the other shows the corresponding values where the ratings come from.

2 Camera Concept Selection

Table 1: Concept Selection Matrix for the camera.

Requirement	**Weight**	**Basler Ace**	**Basler Ace Increased Focal**	**PtGrey Chameleon 3**	**Sony a6000**
Resolution	**3**	2	2	1	5
Weight	**1**	3	3	5	2
Ease of System Integration	**3**	5	5	5	3
Clarity @ 150ft	**5**	1	4	4	5
Stability @ 150ft	**5**	1	1	2	5
Cost	**2**	5	1	4	3
Capture Rate	**2**	3	3	5	2
TOTAL		**50**	**57**	**71**	**86**

3 Measured Camera Values

Table 2: Comparison of relevant camera parameters for different camera candidates.

	Basler Ace	**Basler Ace Increased Focal**	**PtGrey Chameleon 3**	**Sony a6000**
Description	Baseline. The camera from last year with a 12.5mm focal length lens	Last years Basler with a 35mm focal length lens. This decreases field of view, but increases pixels/inch.	Camera from two years ago. Powerful lens, but low Resolution	Camera most commonly used by other AUVSI teams. Low cost, and high resolution
Resolution	5MP	5MP	1.3MP	24MP
Weight	217g	250g	55g	410g
Ease of System Integration	Integrated	Integrated	Previously Integrated	Feasible
Clarity	Blurry, readable	Likely blurry, readable	Readable	Readable
Stability	Target unreadable	Target likely unreadable	Target unreadable	Target readable
Cost	$0	$600	$310	$550
Capture Rate	5Hz	5Hz	30Hz	1Hz

4 Conclusion

The results of the concept selection matrix show that we should use the Sony a6000 for our imaging system. It takes pictures with the highest resolution and takes clear pictures while it is unstable. We will need to put extra effort into integrating it into our system, but it will be well worth it.

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AUVSI Capstone Team (Team 45)

Camera Test Procedures

ID	Rev.	Date	Description	Author	Checked By
TP-002	0.1	10-26-2018	Initial release	Connor Olsen	Tyler Miller
TP-002	0.2	11-9-2018	Feedback edits	Connor Olsen	Tyler Miller

1 Introduction

Due to the flaws discovered with the camera used for the 2018 BYU AUVSI aircraft, it has been determined that a set of tests be outlined to test the effectiveness and reliability of cameras to meet the needs of the imaging team. These tests are designed to prove a camera's ability to show clear images at a long range to facilitate the machine learning algorithm which will identify and categorize targets.

2 Test Objectives

As shown in PC-444, the key success measure for vision is determined by the percentage of targets identified successfully during the competition. To ensure optimal performance, the camera must be capable of capturing high quality pictures at a long range. The following objectives have been laid out to choose a camera that can meet our key success measures:

Focal Length: The camera must be able to focus on targets at a range of at least 150 feet.
Depth of Field: Targets must remain in focus with a tolerance of 50 ft.
Image Clarity: The image must be clear, and its details visible.
Image Stability: The image must remain reasonably clear when camera is unsteady.

3 Required Hardware and Software

- Camera to be tested
- Computer to control camera
- Measuring wheel to measure distance
- Test target with letter

4 Test Procedure

Mount the camera in a location that is sturdy (tripod or on a secure flat surface). Measure 150 feet with the measuring wheel and have someone hold the target with letter at that distance. Have someone capture an image and inspect the quality and detail of the captured target.

Disturb the camera to simulate the instability of flight and capture another image. Inspect the pixels of the image for sharpness and clarity

5 Special Instructions

To eliminate excessive variables, all camera tests (outside of the plane) are performed in the long alleyway between the EB and the CB, using the cement half-wall as a mount for the camera.

6 Test Conclusion

Using the above-mentioned testing procedure, we were able to compare the camera used in last year's competition to other cameras we are considering. Numerical results of these tests are shown in artifact CS-002.

Brigham Young University

AUVSI Capstone Team (Team 45)

Vision Subsystem Concept Definition

ID	Rev.	Date	Description	Author	Checked By
CD-002	1.0	10-25-2018	Initial release	Tyler Miller	Derek Knowles
CD-002	1.1	11-09-2018	Feedback edits	Tyler Miller	Connor Olsen

1 Introduction

Last year's vision subsystem achieved less than 25% of the possible points related to the subsystem. Vision's key success measure for this year is achieving at least 40% classification with a stretch goal of 80%. Given this measure, it was determined that major improvements must be made in both the manual and autonomous recognition systems.

2 Purpose

The competition gives points for correct classification of ground targets' shape, shape color, alphanumeric, alphanumeric color, alphanumeric orientation, and geolocation. Additional points are given if the process between taking the image and submitting the classified image to the judges' server is fully autonomous without the intervention of a human. There is a penalty, however, if false positive targets are submitted to the judges' server. The purpose of these concepts is to maximize accurate classification performance and thus our key success measure.

3 Concept Selected

Vision's competition requirements are complex and as such required multiple concepts to fit into a larger system. After internal discussion, we decided to pursue a base concept of manual and autonomous classification systems running in parallel.

4 Definition

This year's vision team is changing our system architecture for classifying targets which will allow for better communication and organization. Instead of downloading each image and image state onto someone's personal computer, the computer oboard the plane will send image and vehicle state data to a server on the ground. This server will have a compiled database of all images captured and will attach classification data onto each image as it is manually processed. Our autonomous detection script will also be querying the server image database and classifying images. One team member will be monitoring the autonomous output ready to kill the program if it is sending too many false positives (which cause the team to incur a penalty). Our system architecture is outlined in Figure 1.

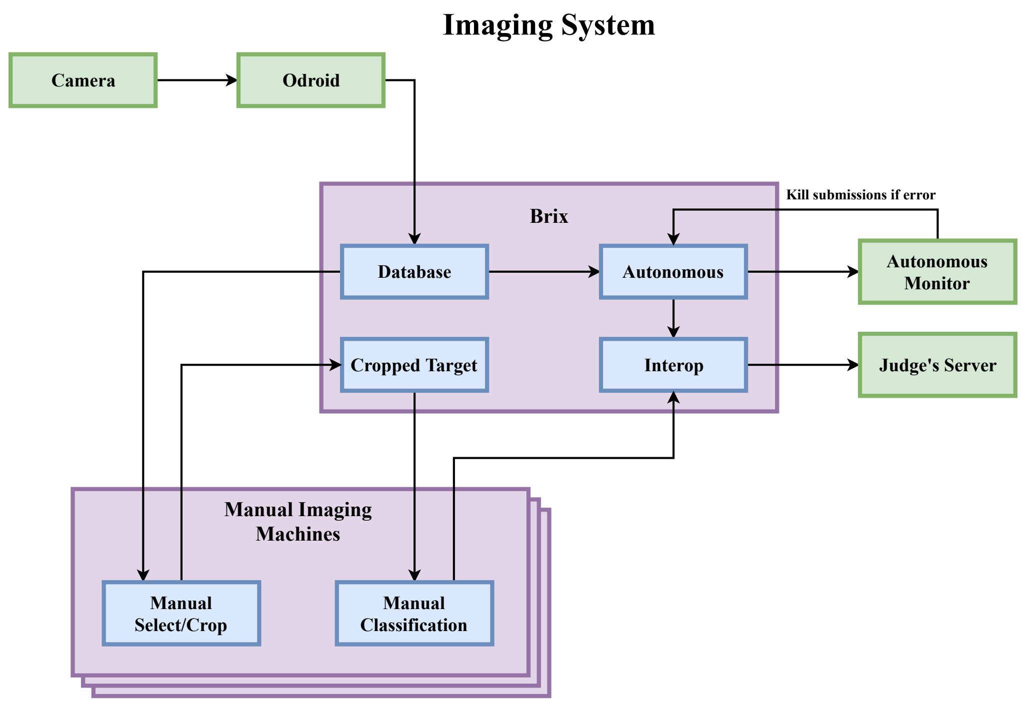

Figure 1: Target classification system architecture

Our autonomous classification system design is outlined in Figure 2. These concepts for autonomous target recognition are based on methods that other competition teams were able to successfully use at the comptition to identify targets. We will continue to iterate on the autonomous process, but we are confident that we can create a reliable and robust system for autonomous target classification.

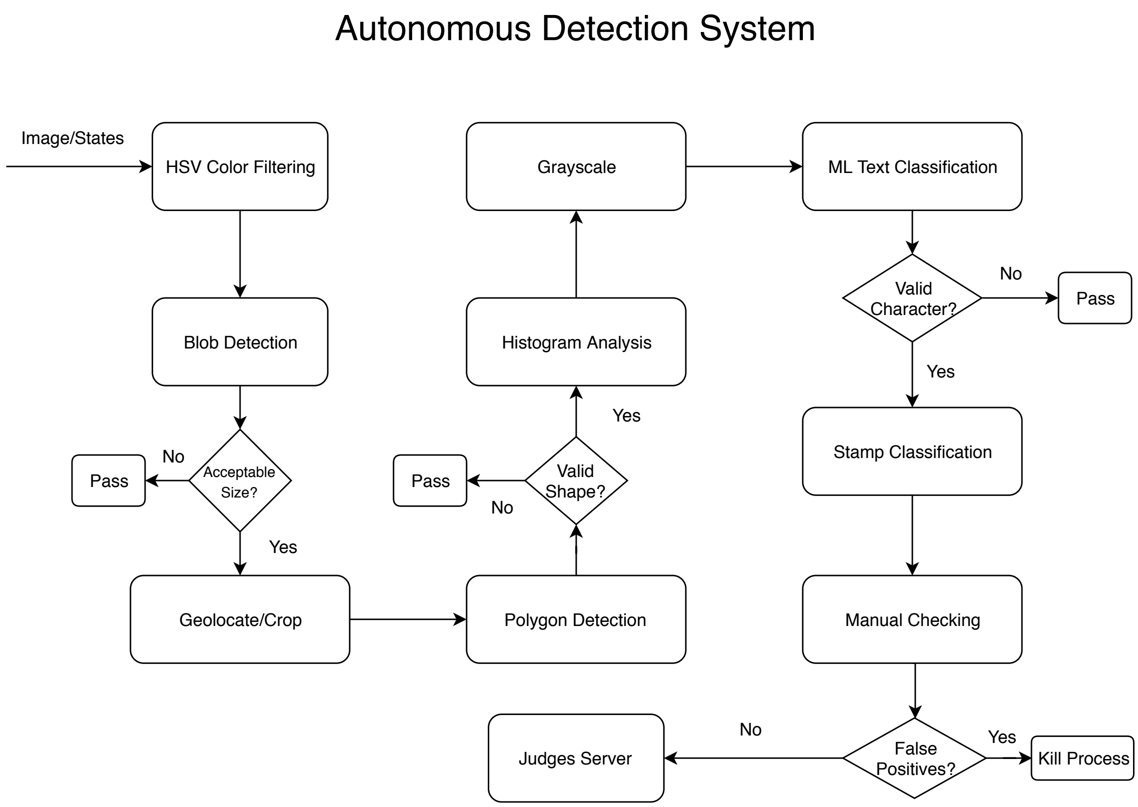

Figure 2: Autonomous classification system design

5 Justification

Since all of our high-level concepts depend on our imaging hardware, we decided it would be beneficial for us to choose a camera as soon as possible. Our list of potential cameras came from previous years systems as well as cameras used by last years top-placing teams. Critical performance measures are shown in our measured camera values table (CS-002). This table was directly translated into a selection matrix (CS-002). Based off the camera concept selection matrix, it was decided that the Sony a6000 would give us the greatest cost to performance. Its large 24MP sensor will improve image quality when flying at higher altitudes and make autonomous classification easier. Its auto-stabilization and fast exposure time also remove a lot of burden from the user to adjust settings mid-flight. Additionally 7 of the top 15 teams used the a6000 or the earlier generation (but basically equivalent) a5100.

The autonomous classification system is the largest undertaking of this year's vision subteam. Each of the 6 characteristics we are required to identify could potentially be done using a different method. Given the high-enumeration of concepts this generates, we determined it would be most beneficial for us to select one high level concept which would help define the rest of the system.

Concepts for autonomous classification were formed in three ways. The first was discussing our system requirements with market experts. They offered excellent advice on how to best go about the classification problem. The second was researching how top-placing teams from previous years tackled the problem. Teams are required to submit a design report which is made publicly available, allowing us understand from a high level how their image classification systems worked. Third, we did extensive online research on available software libraries and tools that could be used. As we pursued these three methods, our best concept for autonomous classification evolved into its current form. We feel that this final concept is the best combination of these three sources.

6 Conclusion

Changes to the vision subsystem will allow us to achieve our key success measure. The winning concepts allow us to reuse much of the code from last year, while improving the reliability and ease of use of the system. The addition of autonomous recognition allows us to maximize possible competition points.