Needs Assessment

Team 12

SOAAR UAV

Small Object Avoidance Autonomous Rescue Unmanned Aerial Vehicle

NORTHROP GRUMMAN

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09/30/2015

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Abstract

This document serves as an outline of Team 12's Small Object Avoidance Autonomous Rescue (SOAAR) Unmanned Aerial Vehicle (UAV). This project aims to create a UAV capable of autonomous flight, object avoidance, target detection and recognition, and delivering a payload. The UAV will perform a simulated search and rescue mission to find a hiker based off of clues left by said hiker, delivering a bottle of water, and communicating the position of the hiker in the Association for Unmanned Vehicle Systems International (AUVSI) Student Unmanned Aerial Systems (SUAS) 2017 Competition. A robust UAV with responsive object avoidance and full autonomy will further the vast innovation in the UAV industry. In order to accomplish all objectives the previous UAV will be used and equipped with a new sensor payload and with a new camera system. Structural modifications will also be completed to allow for payload delivery and increase durability if necessary.

1.0 Introduction

Unmanned Aerial Systems (UAS) have garnered an astounding amount of attention both in government and civilian use in recent years. Large companies, most notably Amazon, plan to utilize Unmanned Aerial Vehicles (UAVs) to deliver goods to customers in a quicker and more cost effective manner while the government is considering UAVs for border patrol, search and rescue missions, and many other applications. However, in order to capitalize on UAV potential reliable and robust autonomous UAVs must be readily available. It is this leap in technology that the Association for Unmanned Vehicle Systems International (AUVSI) aims to impact with the 15th annual Student Unmanned Aerial Systems (SUAS) Competition. The competition requires the development of an autonomous UAV that is capable of autonomous takeoff and landing, securing waypoints, traveling between waypoints autonomously, avoiding stationary and dynamic objects, detecting and classifying targets, delivering a payload undamaged, and detecting an emerging object. The submitted UAV will complete a simulation of a search and rescue mission to find and deliver a bottle of water to a lost hiker.

2.0 Project Description

2.1 Need Statement

SUAS 2017 competition requires a UAV proficient in autonomous flight and navigation, remote sensing via onboard sensors, and carrying out a simulated search and rescue mission for a stranded hiker. Current search and rescue UAVs must be remotely operated, requiring need for manpower and possibly introducing human error. Therefore, a system is needed that can eliminate the need for manpower and human error while increasing efficiency and effectiveness of future search and rescue missions.

2.2 Literature Review

Autonomous UAS have been heavily studied and therefore there is a plethora of knowledge that can be utilized to see this project's potential to fruition. Autonomous ground vehicles also have significant amounts of research that can be applied to target detection, classification of targets, object avoidance, and much more for UAS. The major problems which need to be solved to ensure success in this project are as follows: autonomous flight and navigation, stationary and dynamic object avoidance, off-axis and emergent target detection and classification, and payload delivery capabilities.

In order to achieve autonomy the system must determine the map, boundaries, waypoints, and localization.[1] In our particular competition we will be given the map, boundaries, and waypoints. Therefore the focus of the literature review is on localization in 3-dimensional space. To determine where the system is in relation to the map the system must know where it is located in 3-dimensional space, thus an Inertial Measurement Unit (IMU), Global Positioning System (GPS), and altimeter are necessary.[2] Common means to obtain the altitude in light weight UAS include: ultrasonic sensors and small barometers. While some flight controllers such as the Pixhawk include IMU, GPS, and barometer.[3]

Multiple approaches have been taken to object avoidance for both ground and aerial vehicle configurations. Hardware options outlined in this document include: stereo cameras, LIDAR, and ultrasonic sensor arrays. A project similar to the proposed UAS was conducted by Andrew J. Barry with MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). A pushbroom stereo algorithm, available open source, was utilized alongside 2 Point Grey Firefly MV stereo cameras installed on the inboard leading edge of both UAV wings.[4] The images taken by the cameras are analyzed at 10 meters out in order to reduce processing requirements necessary when processing images at multiple distances away from the UAV. This novel approach allows for less expensive processors with lower power requirements to be used yielding a lighter payload opposed to the configuration needed to use standard block-matching stereo system. However, since stereo cameras rely on imaging the system is prone to disturbance by glare, fog, and other visual impairing conditions leading to a need for a second method of object detection as a fail-safe. LIDAR is a common object avoidance sensor which uses lasers in order to determine the distance objects are from the system using radar principles.[5] LIDAR is used often in intelligent vehicles, especially ground vehicles, but LIDAR can be problematic when used by aerial vehicles. Less common use of LIDAR in aerial vehicles is primarily caused by the typical 2-dimensional detection range and heavy weight when compared to alternatives.[4] An alternative to LIDAR is an ultrasonic sensor array which can face down and outwards to detect approaching objects when the imaging capabilities are compromised. One example of a UAV capitalizing on ultrasonic sensor arrays for object avoidance is the DJI Phantom 4 which has high quality object avoidance for UAV hobbyists.[6] Based upon background research to date, a pushbroom stereo system paired with an ultrasonic sensor array will be most suited for this project.

The SUAS competition requires the detection and classification of alphanumeric symbols placed on different colored shapes as well as the detection of an emerging object (hiker).[7] The focus of the background research for target detection therefore focused on the detection and obtaining characteristics rather than following a target which is popular for drones in the filming industry. First a Pixy camera was considered due to its simple implementation and versatility. After further research it was determined that a Pixy camera does not have sufficient range because it is not capable of detecting and classifying an alphanumeric symbol 250 feet away, as required by the competition.[7-8] This realization led to further research into using more standard cameras and running the imaging through a target detection software in order to detect alphanumeric symbols. There is open source code that can be adapted and used to teach the software various targets by sending different images.[9] A design of experiments could then be developed based upon the details outlined in SUAS competition rules to teach the software all possible target configurations. Convolutional Neural Networks (CNN) are a valid alternative to the software mentioned above and Pixy cameras, however because of their demand of high-end graphics processors they will likely be disregarded for this project if possible.[10] Infrared (IR) cameras could prove useful in detecting the hiker because the open source code is more suited to handle a dynamic target than other open source code created to detect alphanumeric symbols. The software does not have to rely on detecting the object as it is moving, instead it can detect anything putting off more heat than its surrounding (i.e. human, animal) therefore the software can be adapted for this competition in an easier manner.[11] However, the added complexity associated with an IR camera or a camera capable of both IR and standard imaging must be considered.

Research in payload delivery mechanisms has increased recently in the UAS industry, with companies such as Amazon investing capital in the venture. Some deployment systems require autonomy and determine the optimum parameters in which to release the payload with a parachute keeping the payload undamaged.[12] However, this added complexity may is not the only method to deliver an undamaged payload with relatively good accuracy. Other UAS delivery systems take a more conventional approach and release the payload while in a dive opposed to horizontal flight in order to increase speed and accuracy of the payload.[13] The payload can be released by typical mechanical means or through magnetism or more exotic methods. Parachutes and tether ropes both serve as viable solutions to deliver an undamaged payload.

2.3 Goal Statement and Objectives

Develop an autonomous UAV featuring autonomous takeoff and landing, autonomous flight and navigation, target detection and classification, stationary and dynamic object avoidance, and payload delivery.

Project Objectives:

- Test current level of autonomous flight
- Improve level of autonomous flight if necessary
- Assess current structural integrity and capabilities
- Select and install sensor package
- Test sensor package
- Select, install, and test object avoidance cameras and equipment
- Select, install, and test camera capable of target detection
- Modify current structure to support new landing gear and payload delivery mechanism
- Design, build, and install payload delivery mechanism
- Create finite element model of modifications and payload delivery mechanism
- Select and install new landing gear
- Modify open source software for object detection
- Develop control laws to respond to object detection
- Modify open source target detection and classification software
- Modify open source software to detect emerging object (hiker)
- Install equipment necessary to detect emerging object (hiker)

2.4 Constraints

The following constraints are placed on the project by the AUVSI SUAS competition and are outlined in the SUAS Rules and Requirements[7] and the Academy of Model Aeronautics (AMA) National Model Aircraft Safety Code.[14]

- Maximum takeoff weight must be less than 55 pounds.
- Maximum UAS speed must be less than 70 KIAS.
- UAS must comply with (AMA) National Model Aircraft Safety Code.
- UAS must return to land after 30 seconds of lost communication.
- UAS must terminate flight after 3 minutes of lost communication, this will include closed throttle, full up elevator, full right rudder, and full right or left aileron.
- UAS must not use any exotic fuels or batteries.
- All fasteners must have safety wire, Loctite, or nylon nuts.
- No components may fall off UAS during mission with the exception of payload delivery.
- Must have a ground station where a display features a map with boundaries, the UAS position, and all other competition aspects including speed and altitude.

- No objects greater than or equal to 15 feet may be used.
- Must not use any ground-based sensors.
- All radio frequency (RF) communications must comply with Federal Communications Commission (FCC) regulation.
- Must not intentionally interfere with another team's communication.
- Must be capable of operation with 15 knots winds with gusts up to 20 knots.
- Must be capable of operation in temperatures reaching up to 110°F and temperature averaging over 100°F for over 12 hours.

3.0 Methodology

This project will be focused on the autonomy, object avoidance, target detection, and payload delivery. The previous UAV design and build will be used in order to minimize redundancy and maximize budget. Feasibility of the previous UAV design was determined by use of a House of Quality (HOQ) which related the most important competition requirements, determined by each requirements percentage of total possible points, with engineering characteristics associated with the UAV structure. The HOQ is attached in Appendix A. However, upgrades will be made to current camera equipment and a new sensor payload will be selected to allow full capability of the aircraft. Structural modifications will also be made as the final UAV will have a payload delivery mechanism attached that can drop a payload to the hiker. Upon completion of sensor upgrades and structural modifications software will be developed to complete autonomy, object avoidance, and target detection. Proceeding design and development is testing, the software and the system as a whole will be tested to ensure complete integration and capability.

4.0 Conclusion

The AUVSI SUAS competition requires a UAS capable of full autonomy, object avoidance, target detection and classification, and payload delivery. The previous UAV has been assessed and will be used for this year's project. Sensor payload will be integrated, structural modifications will be made, and software developed through the course of this project in order to prepare a system capable of performing well in the AUVSI SUAS competition. The project will require students to fully utilize skills learned over the course of the degree and employ engineering design methods taught in senior design and previous courses. Team 12 is fully committed to applying knowledge learned in this degree to allow the project's potential to see fruition.

References

[1] Roland Siegwart, I. R. (2011). *Introduction to Autonomous Mobile Robots.* Cambridge: The MIT Press.

[2] Lorenz Meier, P. T. (2011). PIXHAWK: A System for Autonomous Flight using Onboard Computer. *IEEE International Conference on Robotics and Automation*.

[3] *Pixhawk Home Page* Retrieved from Pixhawk Autopilot: https://pixhawk.org/modules/

[4] Tedrake, A. J. (2015). Pushbroom Stereo for High-Speed Navigation in Cluttered Environments. *IEEE International Conference on Robotics and Automation*.

[5] Saurabh Ladha, D. K. (n.d.). Use of LIDAR for Obstacle Avoidance by an Autonomous Aerial Vehicle. *IEEE Conference on Robotics and Automation*.

[6] *DJI Phantom 4: Finally an Obstacle-Avoiding, Object-Tracking Quadcopter*. (n.d.). Retrieved from Makezine: http://makezine.com/2016/03/01/dji-phantom-4-finally-an-obstacle-avoiding-object-tracking-quadcopter/

[7] Competition Rules SUAS 2017. (2017).

[8] *Pixy Camera Detect the Colour of the Objects and Track Their Position*. (n.d.). Retrieved from Open Electronics: http://www.open-electronics.org/pixy-camera-detect-the-colour-of-the-objects-and-track-their-position/

[9] Rosebrock, A. (2015, May 4). *Target acquired: Finding targets in drone and quadcopter video streams using Python and OpenCV*. Retrieved from http://www.pyimagesearch.com/2015/05/04/target-acquired-finding-targets-in-drone-and-quadcopter-video-streams-using-python-and-opencv/

[10] Jangwon Lee, J. W. (2015). Real-Time Object Detection for Unmanned Aerial Vehicles based on Cloud-based Convolutional Neural Networks.

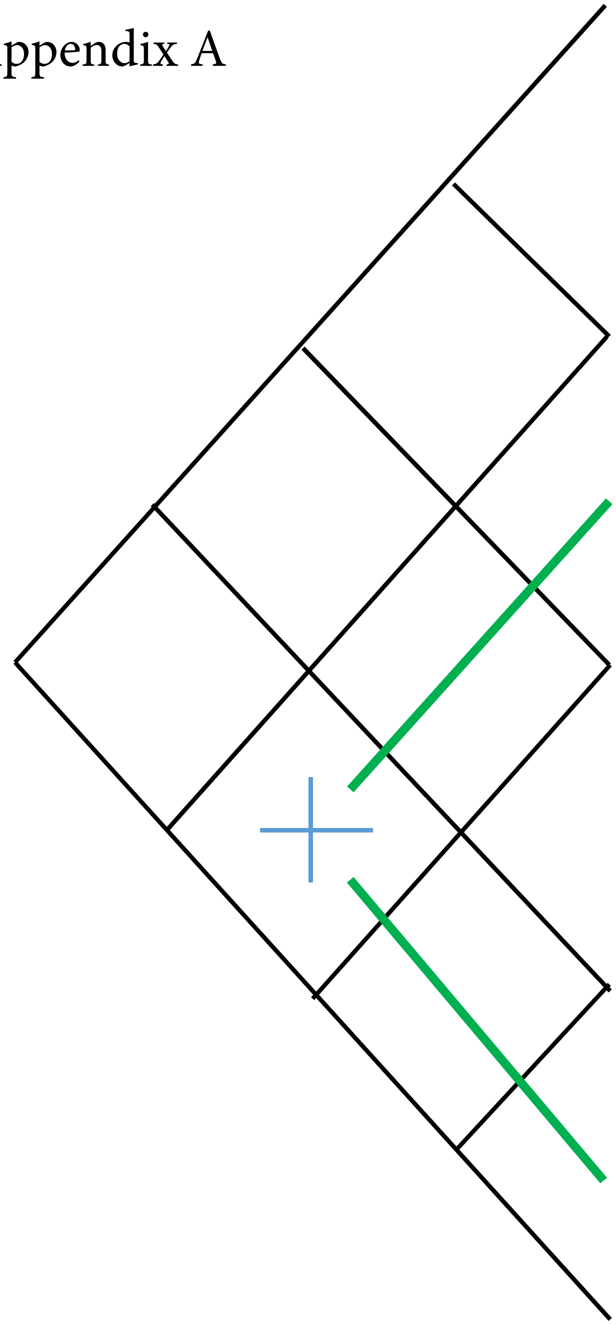
[11] K. Senthil Kumar, G. K. (2011). Visual and Thermal Image Fusion for UAV Based Target Tracking . *InTech Open*.

[12] Oleg A. Yakimenko, E. A. (2015). Autonomous Aerial Payload Delivery System "Blizzard". *21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar.* Dublin,Ireland.

[13] Chris Archer, O. Y. (2012). Enhancing SOF through UAV Pinpoint Payload Delivery. *SOF Mobile Systems Focus Day.* San Diego.

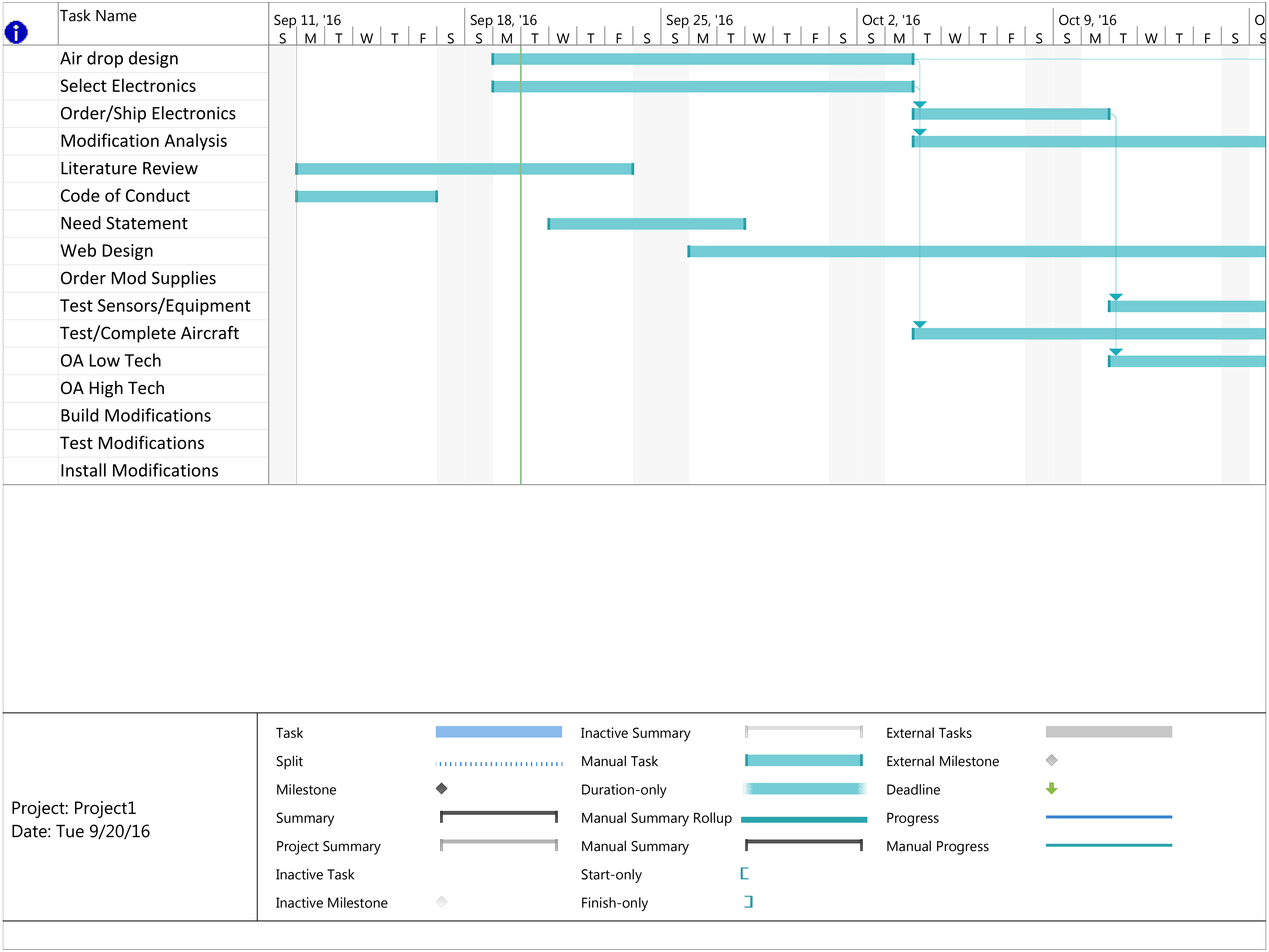
[14] Academy of Model Aeronautics National Model Aircraft Safety Code. (2014, January 1).

Appendix A



		Engineering Characteristics			
CR	CI	Electronics Storage	Durability	Imagining System	Payload Mechanism
Affordability	3	2	1	10	5
Safety	5	4	10	8	5
Autonomy	5	10	1	5	1
Object Avoidance	4	10	1	10	1
Payload Delivery	2	1	5	1	10
Target Detection	4	10	1	10	1
Score		158	76	177	73
Relative Weight		32.6	15.7	36.6	15.1
Rank		**2**	**3**	**1**	**4**

CR - Competition Requirements
CI - Competition Importance
1(low) - 5(high)
Engineering Characteristics
1(low) - 10(high)


Task Name
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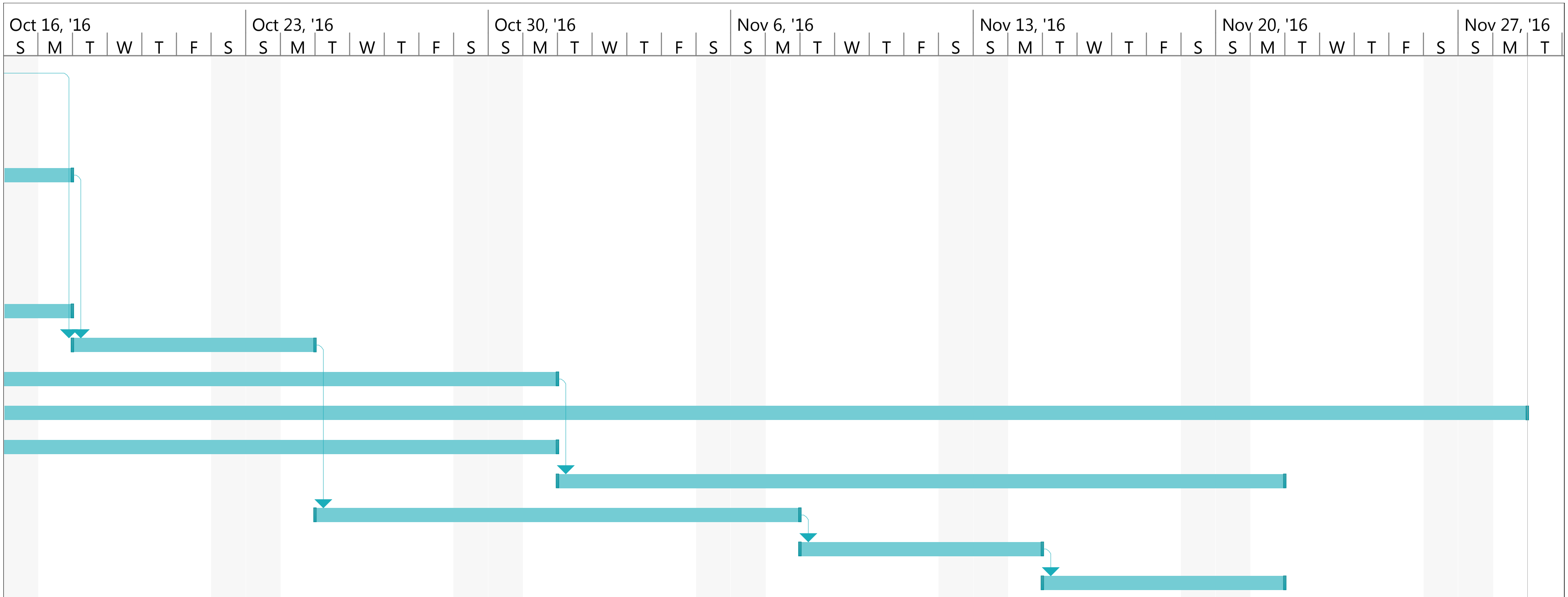
Sep 18, '16
Sep 25, '16
Oct 2, '16
Oct 9, '16
S M T W T F S
Air drop design
Select Electronics
Order/Ship Electronics
Modification Analysis
Literature Review
Code of Conduct
Need Statement
Web Design
Order Mod Supplies
Test Sensors/Equipment
Test/Complete Aircraft
OA Low Tech
OA High Tech
Build Modifications
Test Modifications
Install Modifications
Project: Project1
Date: Tue 9/20/16
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress



Project: Project1
Date: Tue 9/20/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	