BRIGHAM YOUNG UNIVERSITY

AUVSI CAPSTONE TEAM (TEAM 45)

Subsystem Engineering Artifacts

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Brigham Young University

AUVSI Capstone Team (Team 45)

Capstone Project Contract

Andrew Torgesen, Team Member

Ryan Anderson, Team Member

Derek Knowles, Team Member

Jake Johnson, Team Member

Brady Moon, Team Member

Tyler Miller, Team Member

Andrew Ning, Team Coach

Tim McLain, Sponsor

Kameron Eves, Team Member

Tyler Critchfield, Team Member

Connor Olsen, Team Member

John Akagi, Team Member

Jacob Willis, Team Member

Brandon McBride, Team Member

Brian Jensen, Capstone Instructor

Contents

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 12th to 15th, 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 10th overall while the 2018 team was a Capstone team and placed 9th 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

Team Member Name	Team Position	Contact Information
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Brady Moon	Controls/Payload Team	bradygmoon@gmail.com 435-828-5858
Tyler Miller	Vision Team	tylerm15@gmail.com 385-399-3472
Ryan Anderson	Controls/Payload and Airframe Team	rymanderson@gmail.com 208-789-4318
Jake Johnson	Vision Team	jacobcjohnson13@gmail.com 801-664-7586
Tyler Critchfield	Controls/Payload and Airframe Team	trcritchfield@gmail.com 206-939-8274
Jacob Willis	Controls/Payload Team and Safety Officer	jbwillis272@gmail.com 208-206-1780
Connor Olsen	Vision Team	connorolsen72@gmail.com 385-230-3932
Kameron Eves	Controls/Payload Team	ccackam@gmail.com 702-686-2105

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 Subsystem Interface Definition

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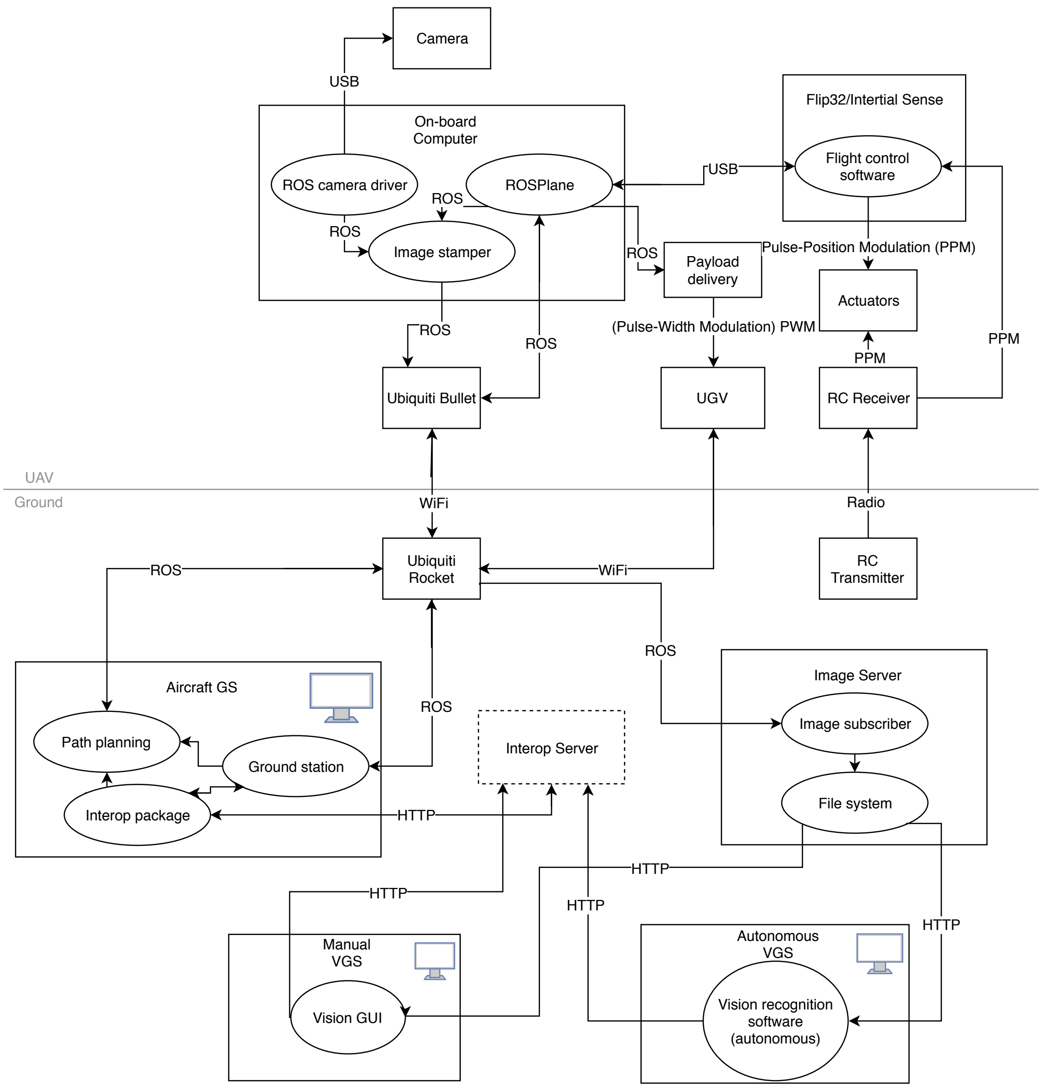

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As can be seen from Figure 1, both radio and WiFi will be used to facilitate connection between the subsystems on the ground and in the air. The Ubiquiti data link allows for communication between the ground and the aircraft over a WiFi network. A 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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Flight Test Log

ID	Rev.	Date	Description	Author	Checked By
AF-004	0.1	11-07-2018	Created*	Kameron Eves	Andrew Torgesen
AF-004	0.2	2-5-2019	Added tracking of autonomous and total flight time	Kameron Eves	Andrew Torgesen
AF-004	0.3	2-5-2019	Added Takeoff/Landing Tracker	Kameron Eves	[Checker]

*Note that additions to this log will not necessitate a revision update. Only formatting or other content changes will require that.

Log

Table 1: A log of each flight test conducted by our team. Autonomous flight time is listed in bold under the total time.

Date (m-d-y)	**Location**	**Length** Total **Auto** **(min)**	Takeoffs/ Landings **Auto**	**Notes**
10-16-18	Springville	<1	1/0	Networking issues, later determined to be because of location. Moving down the road works. Attempted RC flight and crashed on launch. Need to practice launch procedure.
10-19-18	Springville	<1	1/0	Attempted RC flight for imaging. RC lost upon launch. Later determined to be because of the RC antenna not being installed. Aircraft did not have a balanced CG and so performed a loop and crash landed.
10-23-18	Springville	1	1/0	Attempted RC flight for imaging. Aircraft had major longitudinal stability issues. Later determined to be because of a negative static margin. Moving the batter forward fixes issue. Lost control and crashed. Transmitter also dying very very quickly. Later determined to be transmission power set to high (1 A changed to 10 mA).
11-01-18	Springville	3	1/0	Attempted RC flight for imaging. Still had minor stability issues. We lost control and crash landed near end of flight. We later determined these issues were because the battery was not secured properly. It slid around inflight affecting our static margin. This caused instability and aggressive flight maneuvers that caused the battery to fall out in flight. As such we lost control and crashed. Battery must be strapped down.

11-06-18	Springville	5	1/0	Attempted RC flight for imaging. Aircraft flew wonderfully. Images of ground targets successfully captured. Flight was terminated when RC was lost and aircraft crashed hard. More investigation into the cause is needed. Possibly because of RC interference over the trees or to low of transmission power.
12-11-18	Rock Canyon	1	1/0	First flight test of new aircraft. Performed a glide test and found the aircraft performed well. With slight longitudinal instability. We moved the cg forward by adding a 500 g weight. This proved too much as the aircraft was notably nose heavy the next flight attempt which was forced to landed immediately upon takeoff . With an inexperienced pilot, we found this preferable to instability and attempted a second flight. The aircraft still dropped on takeoff but stable flight was obtained. This lasted 45 seconds before the pilot lost control and crashed. While pilot error likely played a part in this crash, we later determined that wind from the canyon was a large factor. We will avoid rock canyon in the future.
1-11-19	Rock Canyon	6	1/1	First fully successful flight. Set trims. We also decided to add colored tape to the wings to increase the visibility of the aircraft in flight.
1-18-19	Rock Canyon	4	1/1	Very windy, probably shouldn't have attempted flight but we had not yet figured out the wind problem from the canyon. Adjusted trims.

1-23-19	Rock Canyon	14	2/2	Performed two flights both of which were successful. Several minor repairs (general maintenance) were necessary after this flight. This flight test proved the aircraft was flyable and stable with all of the weight that will be on the aircraft during the competition. We tested both the weight with and without the UGV.
1-25-19	Rock Canyon	11	2/2	Trimmed aircraft with and without UGV weight. Transferred these trims to ROSflight. 2 flights. Additional tape on wing provided sufficient visibility.
1-31-19	Utah County Airfield	7	1/1	Intended to test autopilot and begin tuning gains. Could not successfully turn on autopilot. Later this was determined to be because we were incorrectly following the process to hand over control to the autopilot. We flew once manually to test the gains. Small adjustments were made and transferred to ROSflight.
2-2-19	Utah County Airfield	24 **1**	2/2	Two flights to tune gains on autopilot. The autopilot had a tendency to flip the aircraft upside down immediately after turning on the autopilot. This was determined to not be caused by the gains. Aircraft landed safely manually both flights. After a couple of days of testing we found the cause was that the number being used to convert rad to PWM for the ailerons was negative. This effectively reversed the aileron polarity. Last year the wires must have been swapped from how we have them now.

2-6-19	Utah County Airfield	17 **4**	2/2	Two flights to tune gains on autopilot. Flipping issue was fixed. Aircraft dove towards the ground upon turning on autopilot. This was fixed between flights (rad to PWM conversion for the elevator was negative this time) and we achieved autonomous flight the second attempt. We then tuned the longitudinal PID gains. Aircraft landed safely manually both flights.
2-6-19	Utah County Airfield	31 **10**	1/1	Tuned longitudinal gains and made a small effort to tune lateral gains. We also attempted a loiter, but aircraft was not tuned well enough to do so. Used course following to perfect the gains. Finished the longitudinal gains and got lateral gains reasonable. Next step is attempting a loiter and waypoints to tune lateral gains.
2-19-19	Rock Canyon	3	1/1	Short flight to test cargo drop. Payload dropped upon command and the parachute opened successfully.

Statistics

Total Flight Time: 2 Hour 7 Minutes

Manual Flight Time: 1 Hour 52 Minutes*

Autonomous Flight Time: 15 Minutes

Percent of Autonomous Flight: 11.8%

Manual Takeoffs: 19*

Manual Landings: 13*

Autonomous Takeoffs: 0

Autonomous Landings: 0

Percent of Flights Ending in Crash: 31.6%

Flights Sense Last Crash: 13

*With the aircraft configuration and safety pilot to be used in the competition

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Field Flight Checklist v1.0

ID	Rev.	Date	Description	Author	Checked By
PF-001	0.1	11-03-2018	Wrote checklist based on google sheet and research	Andrew Torgesen	Brandon McBride
PF-001	0.2	01-07-2019	Updated checklist based on team feedback	Andrew Torgesen	Tyler Miller
PF-001	1.0	02-04-2019	Removed redundant checks and added RC override info	Andrew Torgesen	Kameron Eves

1 Purpose

The purpose of this artifact is to keep an up-to-date, standard protocol for ensuring safety and good performance for test flights in hardware. It is important that all test flights are run systematically, and according to the procedures and timelines outlined in this document.

2 Checklist

Day Before

- ☐ Check that the launch file does what it needs to with the plane grounded
- ☐ Ensure that the ROSbag records the data you want
- ☐ Charge airplane LiPo(s)
- ☐ Charge RC transmitter battery
- ☐ Parameter check
- ☐ Check WiFi config
- ☐ Check disk space on Odroid

Hardware Packing List

- ☐ Plane
- ☐ Wings
- ☐ Airplane batteries
- ☐ RC transmitter
- ☐ RC transmitter batteries
- ☐ 2+ sets of props
- ☐ Fiber tape
- ☐ Launch gloves
- ☐ Wrench for props
- ☐ Pliers

- ☐ Battery monitor
- ☐ Safety glasses
- ☐ Screwdriver
- ☐ Table (optional)
- ☐ Targets (optional)

Comms Packing List

- ☐ Router + power cable
- ☐ Litebeam + 2 ethernet cables
- ☐ A/C POE adapter
- ☐ Extra ethernet cable
- ☐ Car power adapter
- ☐ 3-plug extension cable
- ☐ Walkie-talkies
- ☐ Generator (optional)

Flight Checklist: *Before Launching*

Before Powering Motor:

- ☐ Start network
- ☐ Attach wings
- ☐ Attach props and check tightness
- ☐ Strap down battery
- ☐ Connect battery monitor (full battery: 16.8 V)
- ☐ Check plane CG
- ☐ Turn on transmitter
- ☐ Connect battery
- ☐ Ensure network connection

- ☐ Launch ROS (through *screen*, if possible) (ensure aircraft is level)
- ☐ Ensure GPS Fix ($\geq$ 3 satellites)
- ☐ Calibrate Sensors
  - ☐ IMU: rosservice call */calibrate_imu*
  - ☐ Airspeed: rosservice call */calibrate_airspeed*
  - ☐ Barometer: rosservice call */calibrate_baro*
  - ☐ Check attitude estimation (except for yaw–if wrong, update ins offset)
  - ☐ Check airspeed
  - ☐ Check GPS
- ☐ Check RC
  - ☐ Ensure RC transmitter is emitting enough power ($> 10\ mW$, 1 W in competition)
  - ☐ Wire wiggle test
  - ☐ Check control surface direction
    - ☐ Ailerons
    - ☐ Elevators
  - ☐ RC Range Test (100ft, just do this once per setting config change)
- ☐ Lock shut hatch covers
- ☐ Check Autopilot
  1. Begin with throttle 0%, Arm OFF, RC Override ON (both top switches toward the pilot)
  2. ROStopic echo */status*
  3. Secure aircraft (hold firmly)
  4. Arm ON
     - ☐ Confirm *armed* = *true*
  5. RC Override OFF
  6. Perform the following in quick succession (no longer then 2 seconds)
     (a) Call "Clear Props"

(b) Throttle to full

- ☐ Confirm *RC Override = false*
- ☐ Confirm air blowing towards tail

(c) Throttle to idle

- ☐ Confirm prop direction

FLY

- ☐ Takeoff
  - ☐ Ensure area clear
  - ☐ Get into position
  - ☐ Go/No Go Call
    - ☐ Vision
    - ☐ UGV
    - ☐ Autopilot
    - ☐ Antenna Pointer
    - ☐ RC Pilot
    - ☐ Launcher
    - ☐ Team lead
  - ☐ Arm ON
  - ☐ RC Override OFF
  - ☐ Throttle full
  - ☐ Toss the aircraft
- ☐ RC Takeover
  - ☐ RC Override ON
  - ☐ Throttle to desired
- ☐ Handover to Autopilot
  - ☐ RC Override OFF

- ☐ Throttle to full

Flight Checklist: *After Landing*

- ☐ Kill ROS
- ☐ Backup ROSbag
- ☐ Clean shutdown
- ☐ Unplug battery
- ☐ Gather all items

Post-flight

- ☐ Set battery to storage voltage

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UAS Subsystem Interface Definition

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SS-001	0.1	10-25-2018	initial draft	Andrew Torgesen	Jake Johnson & John Akagi
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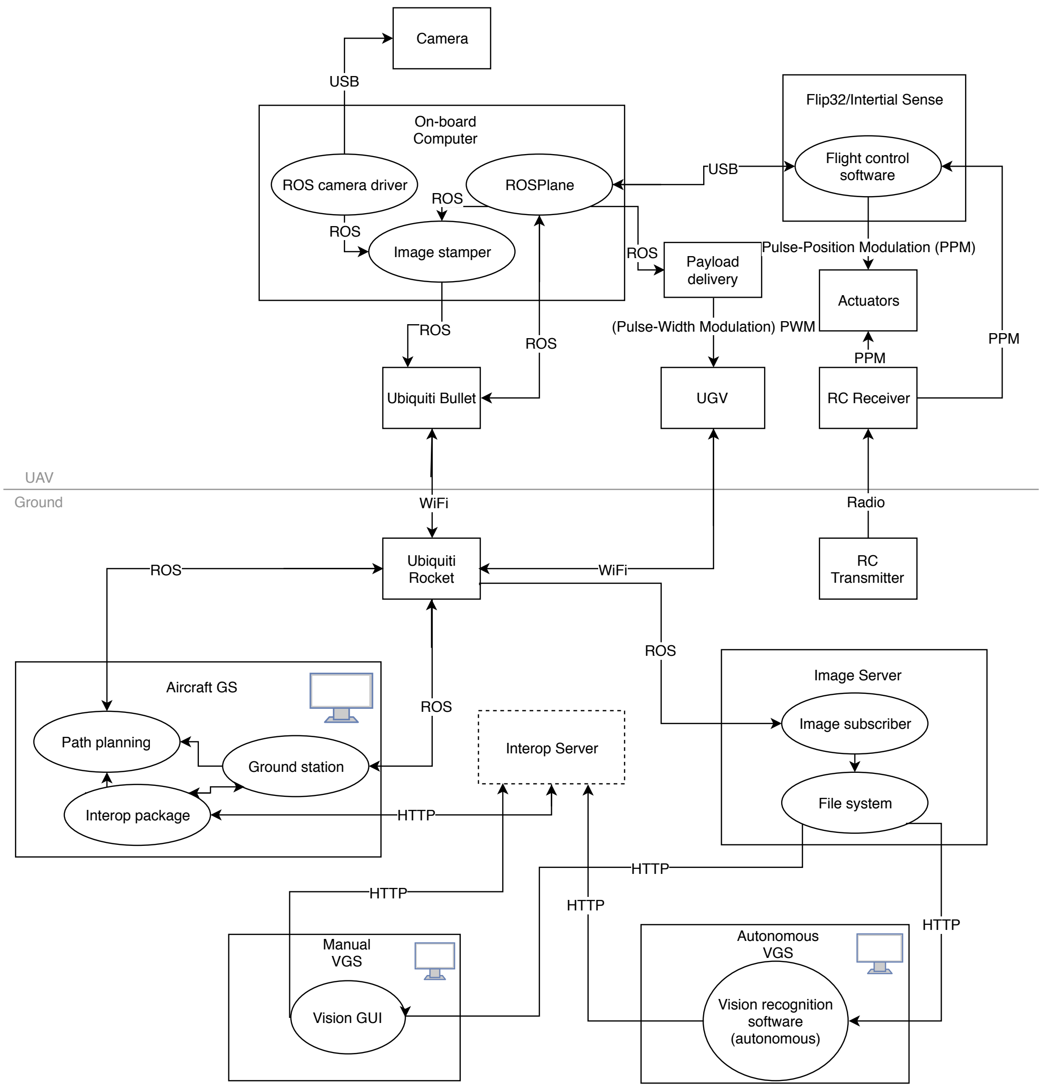

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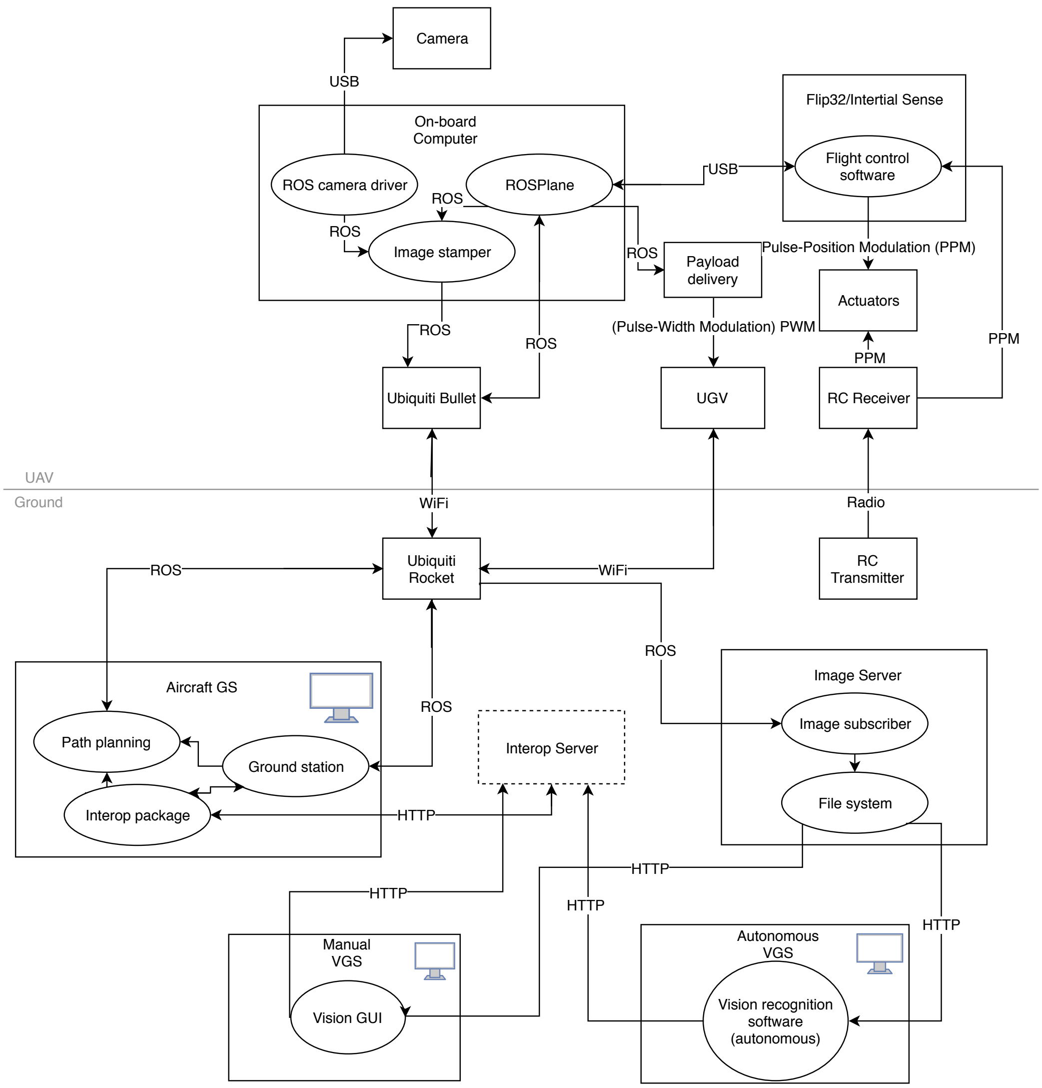

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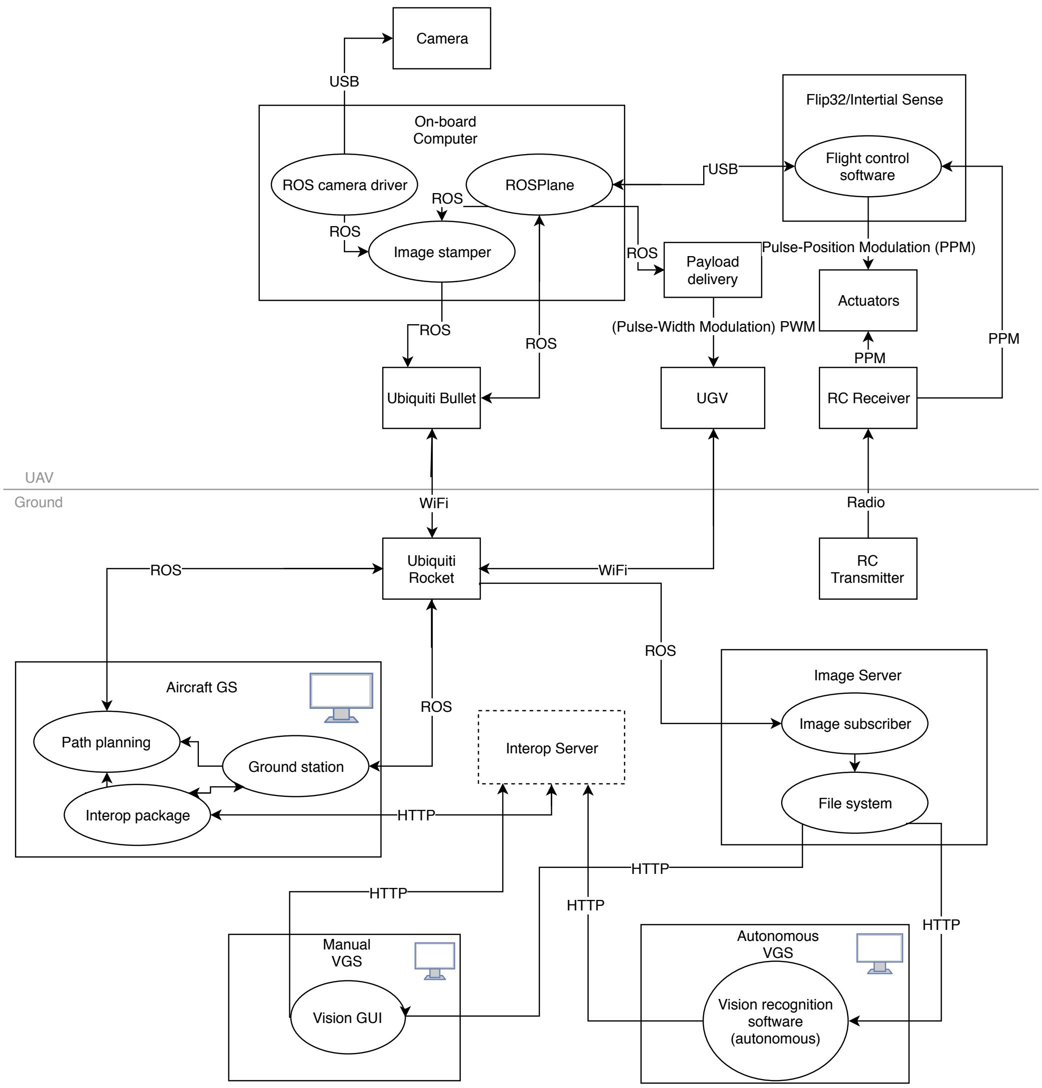

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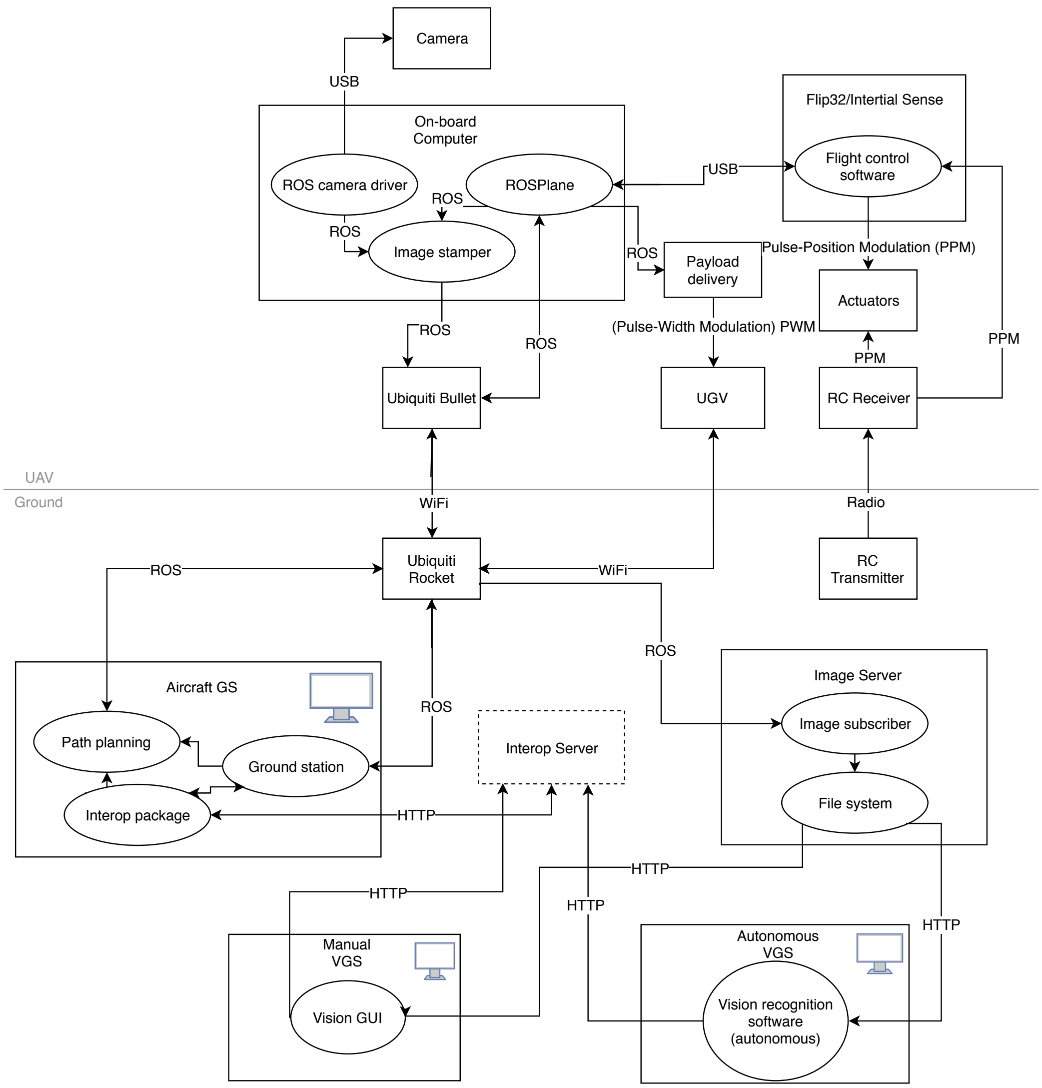

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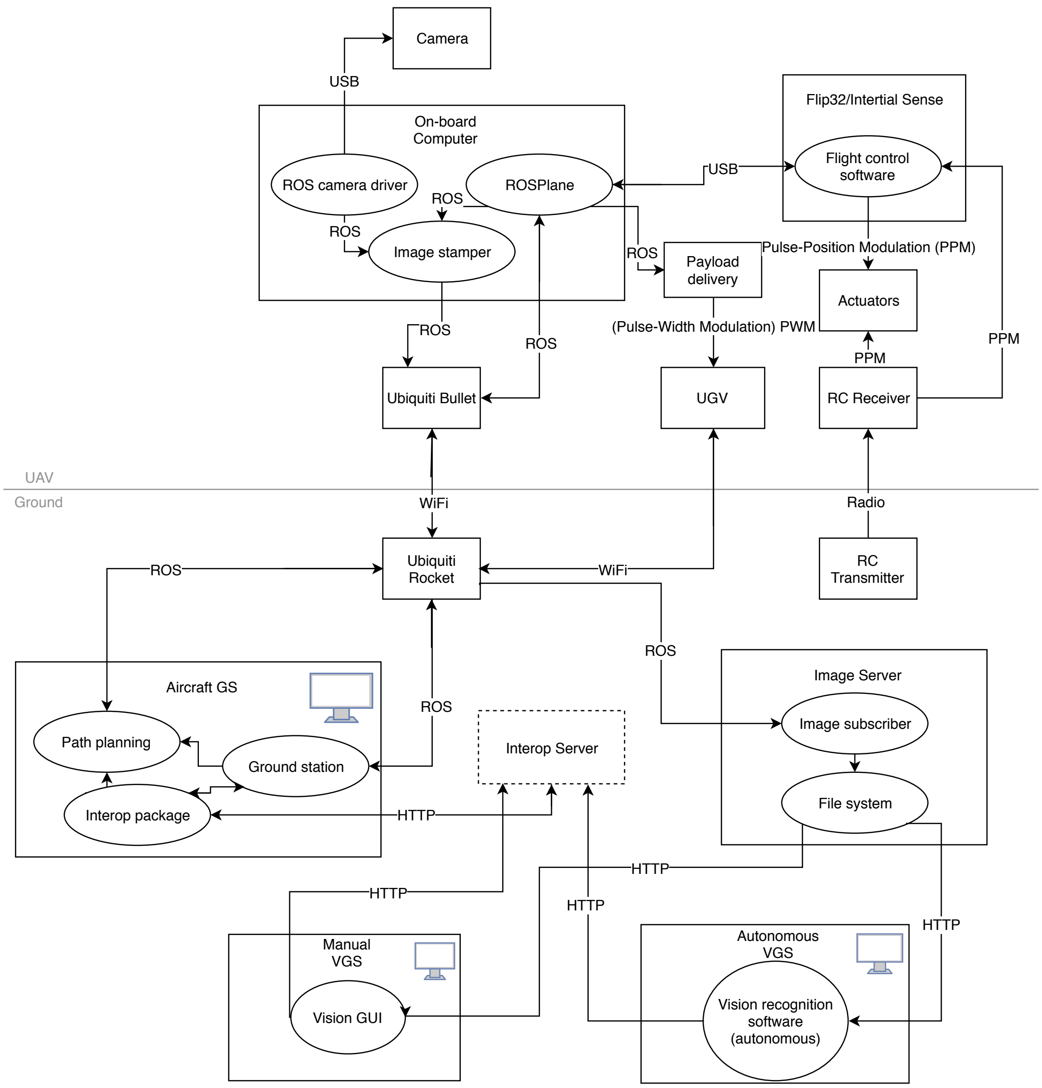

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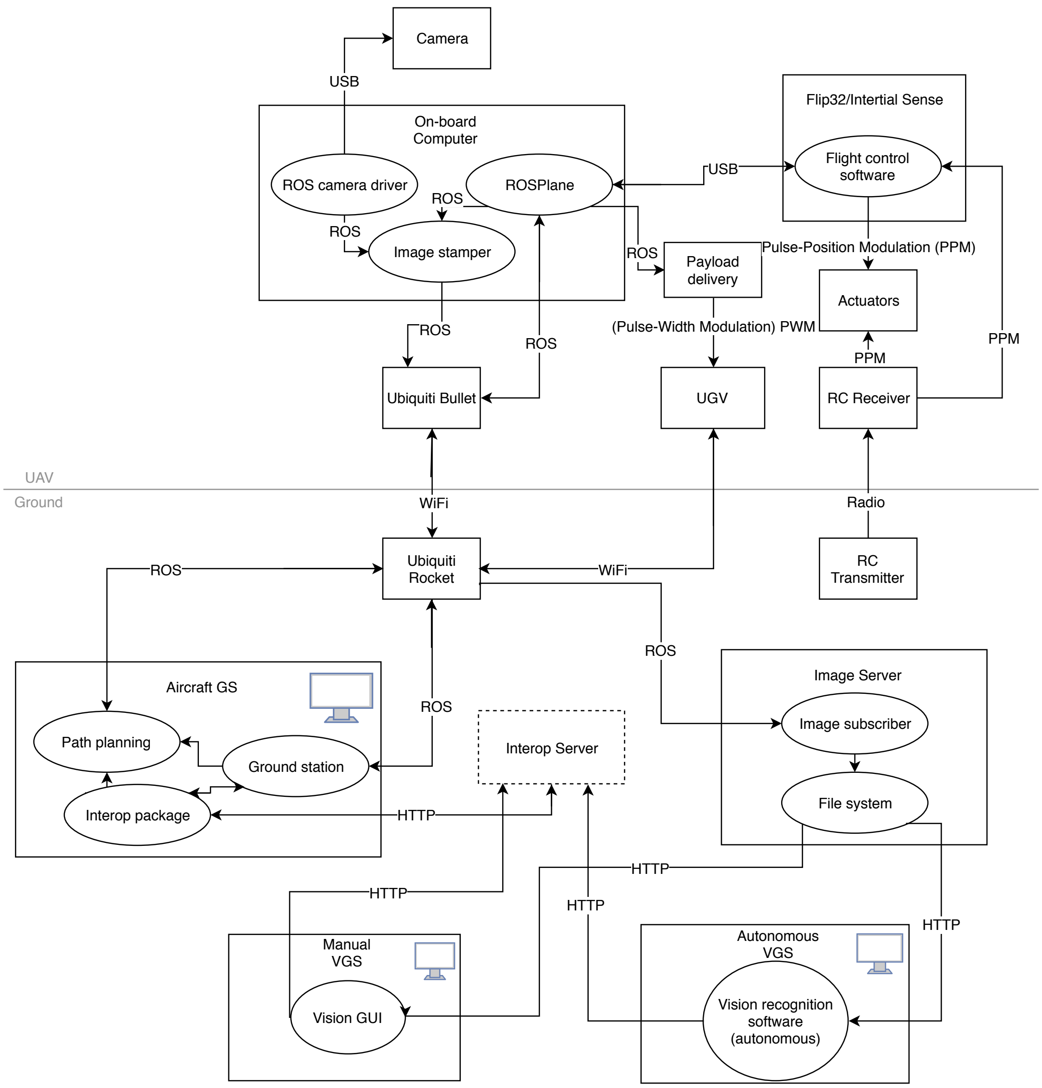

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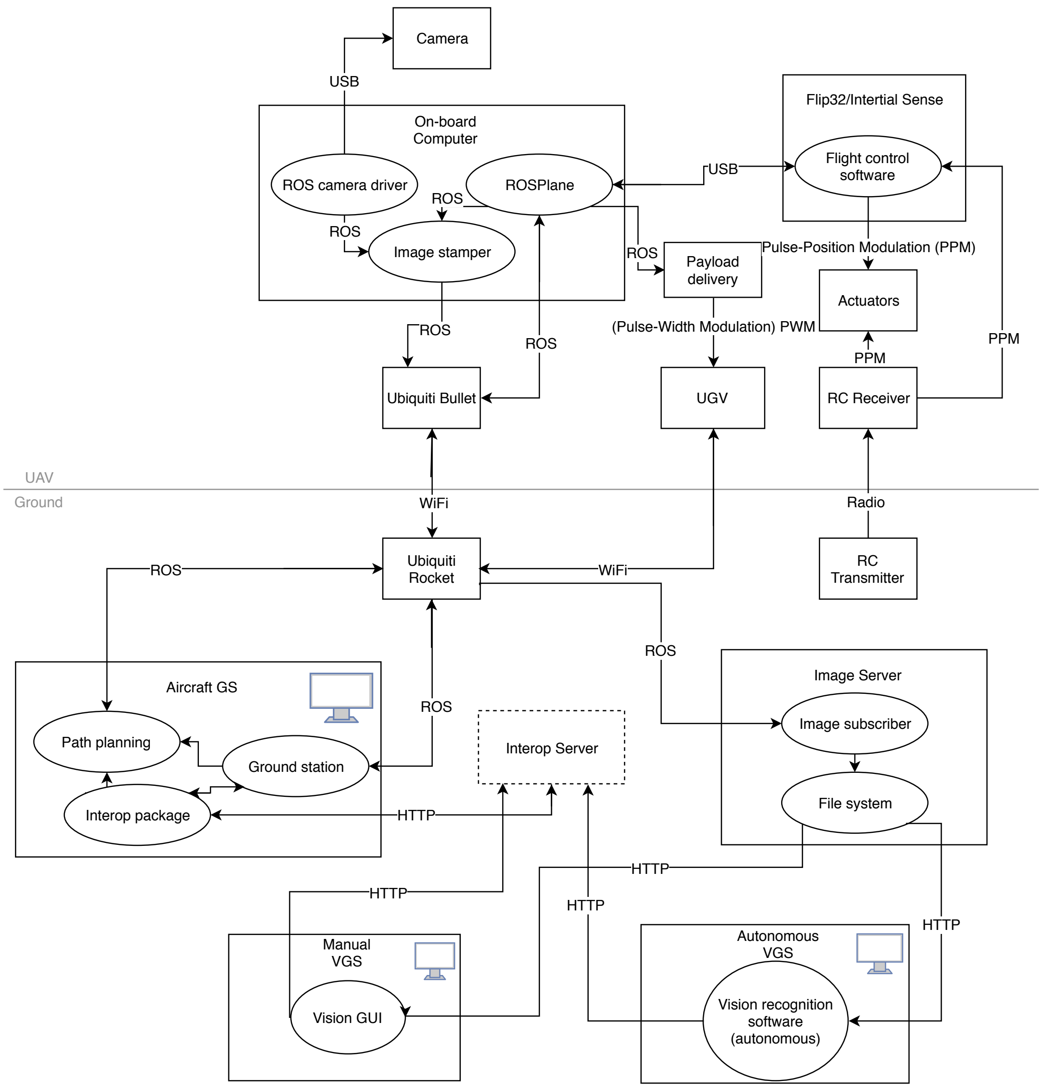

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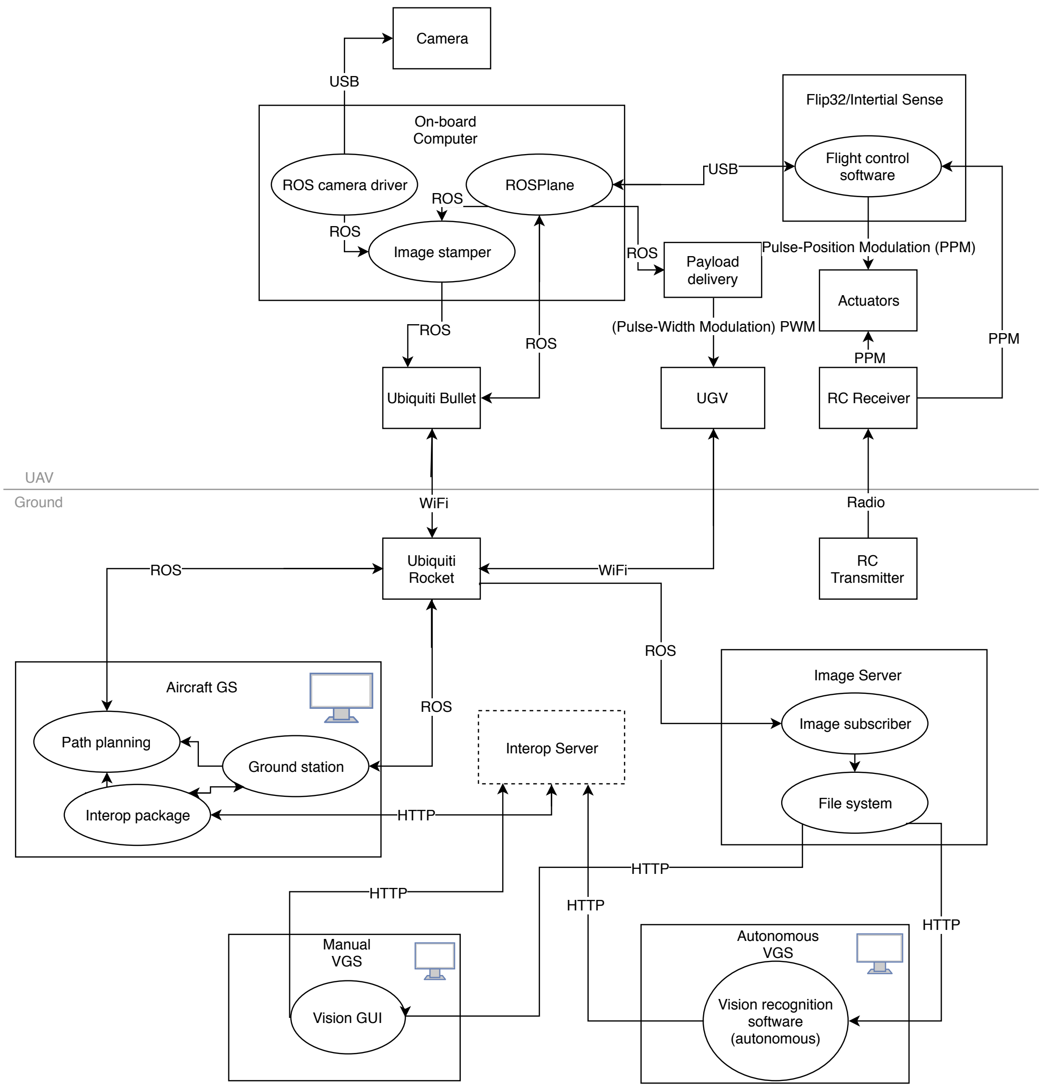

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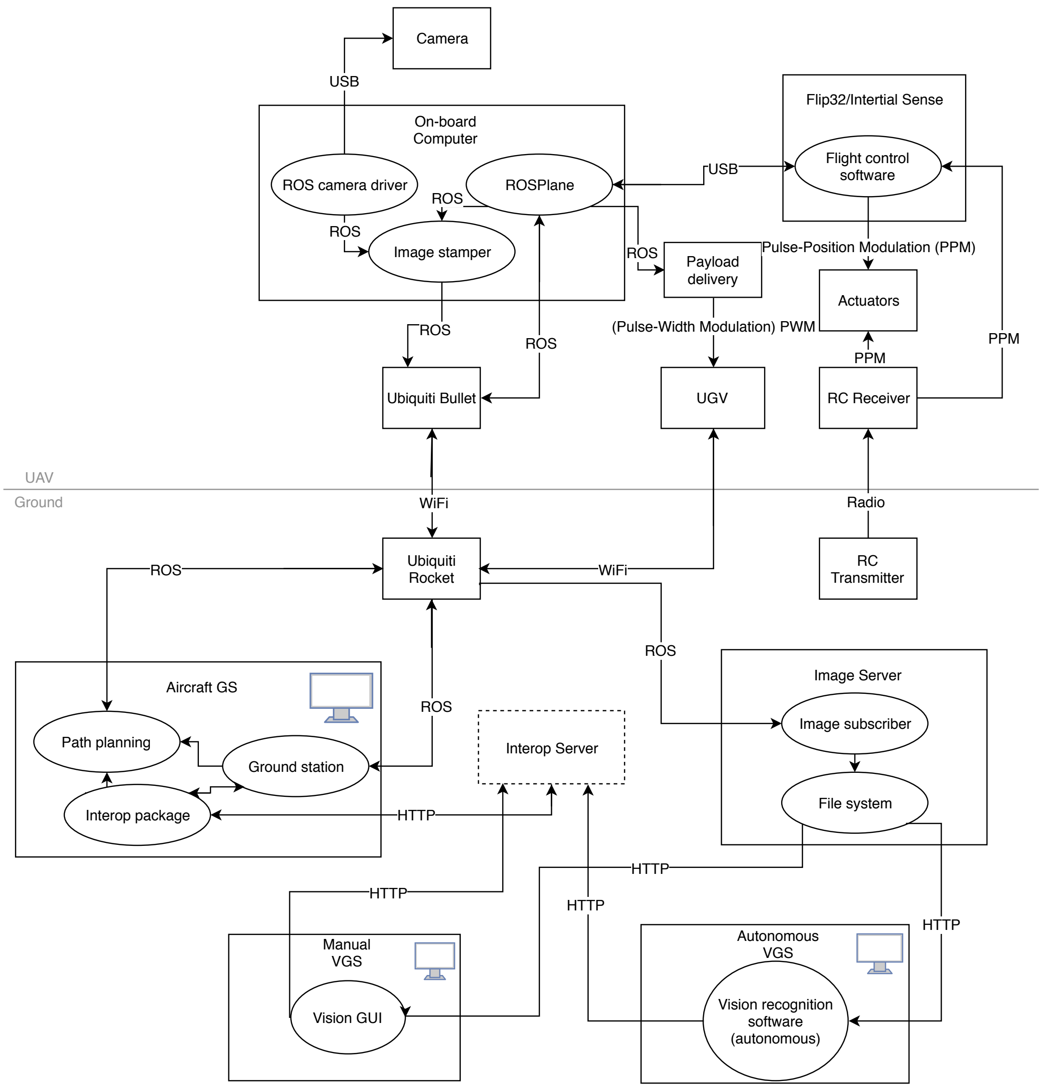

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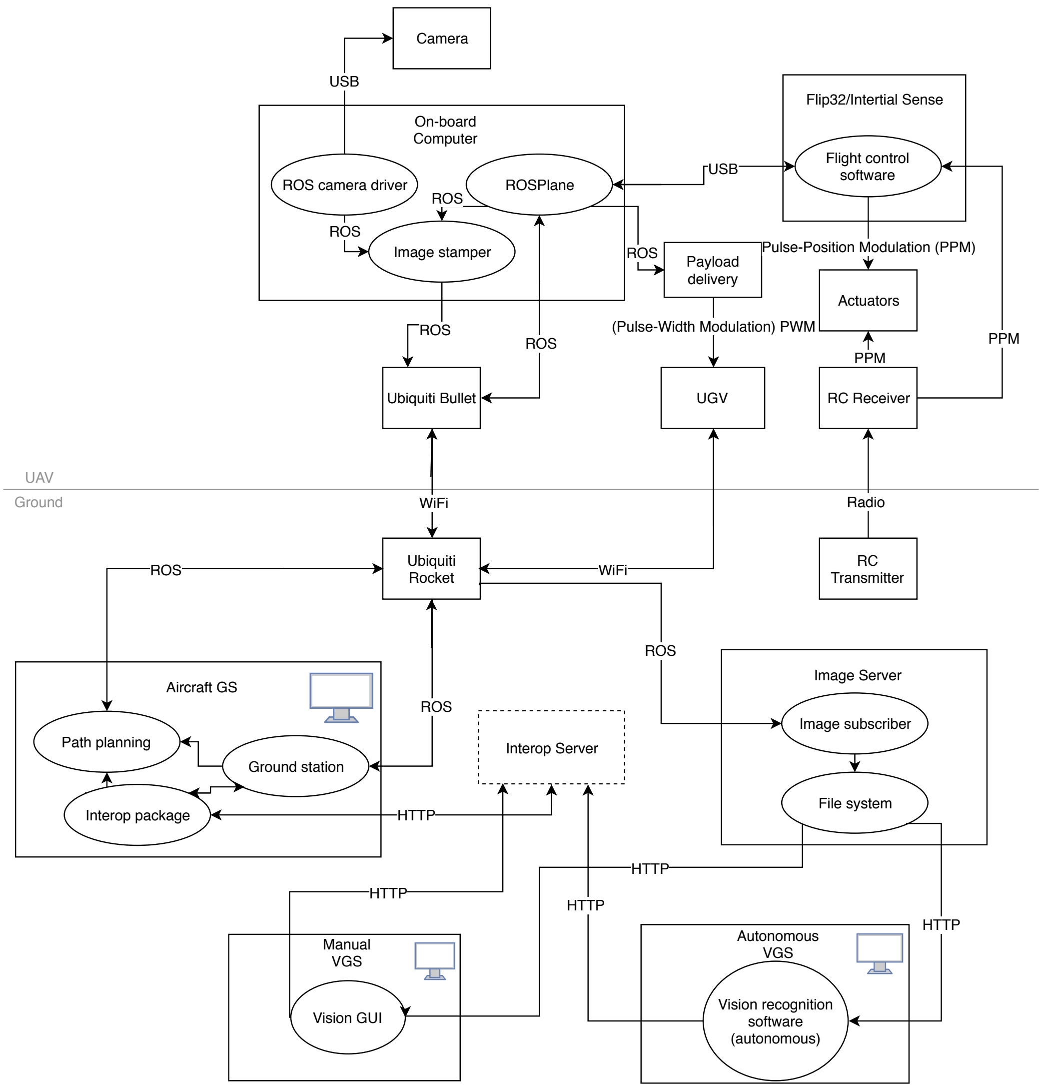

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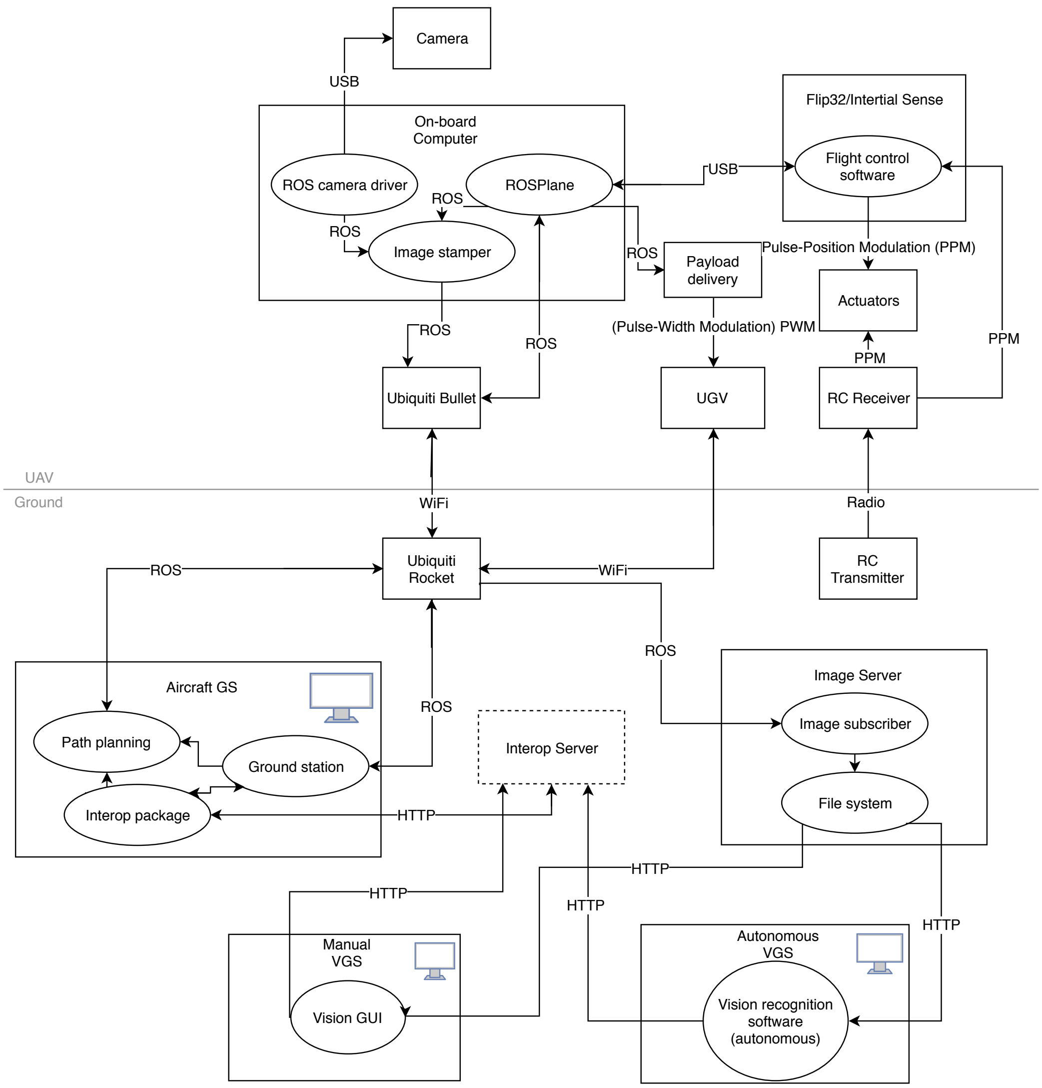

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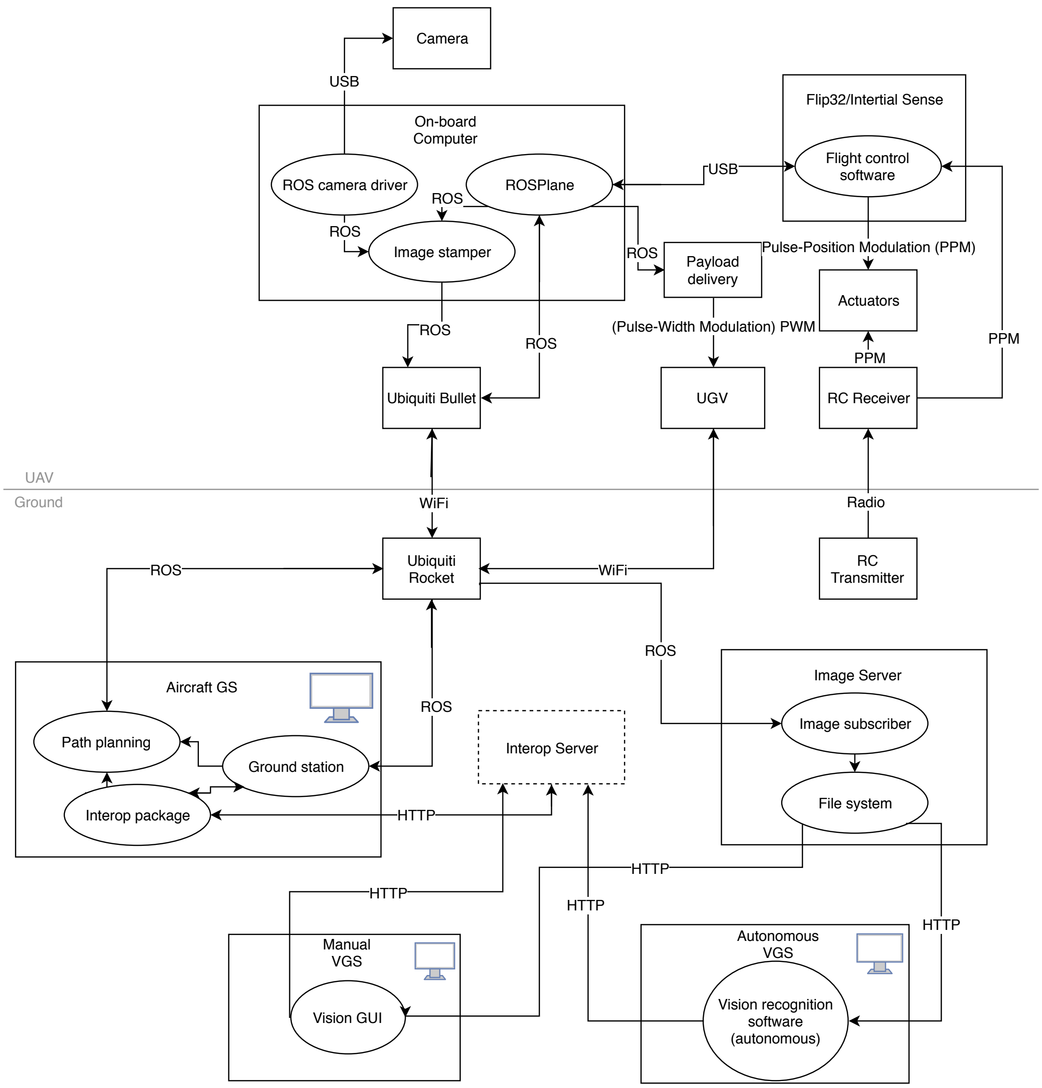

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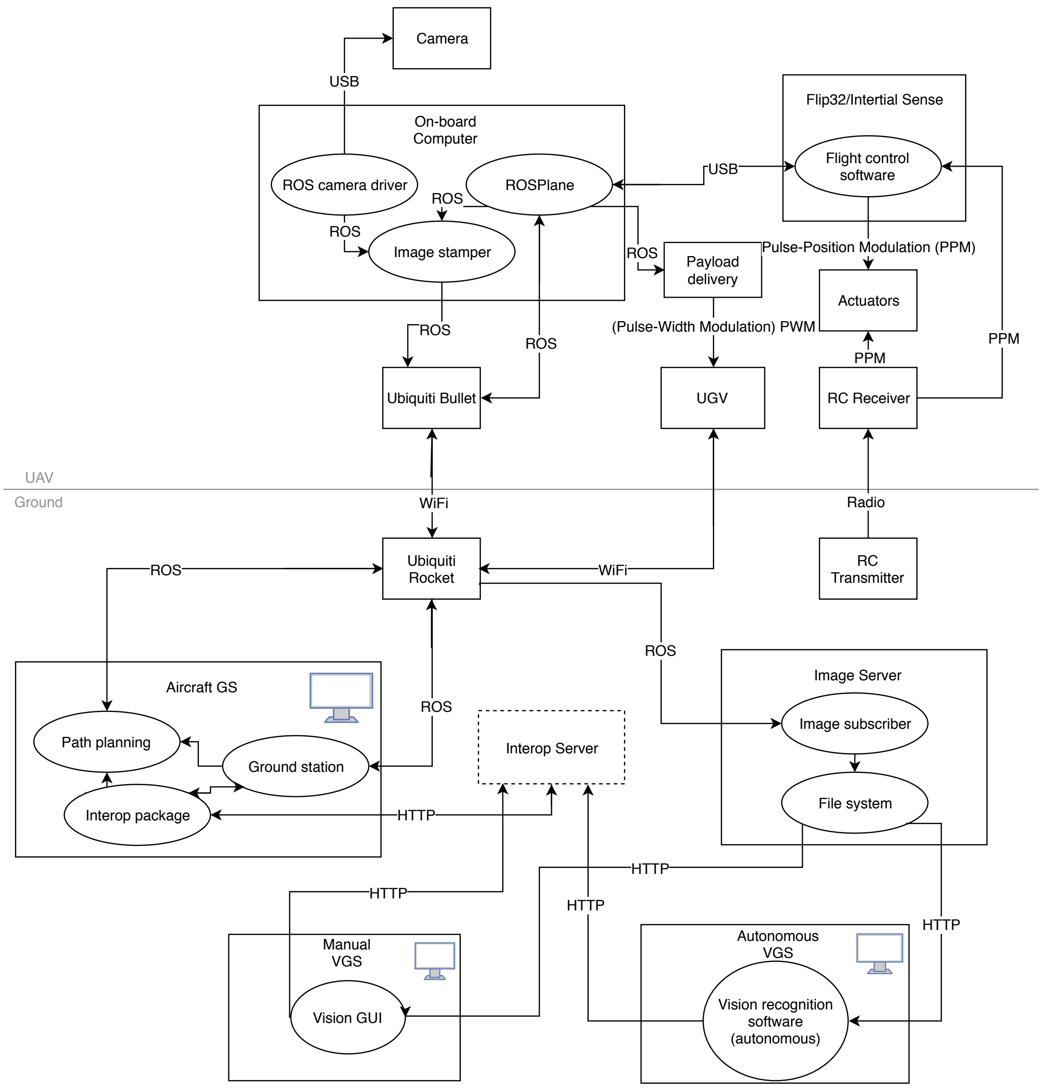

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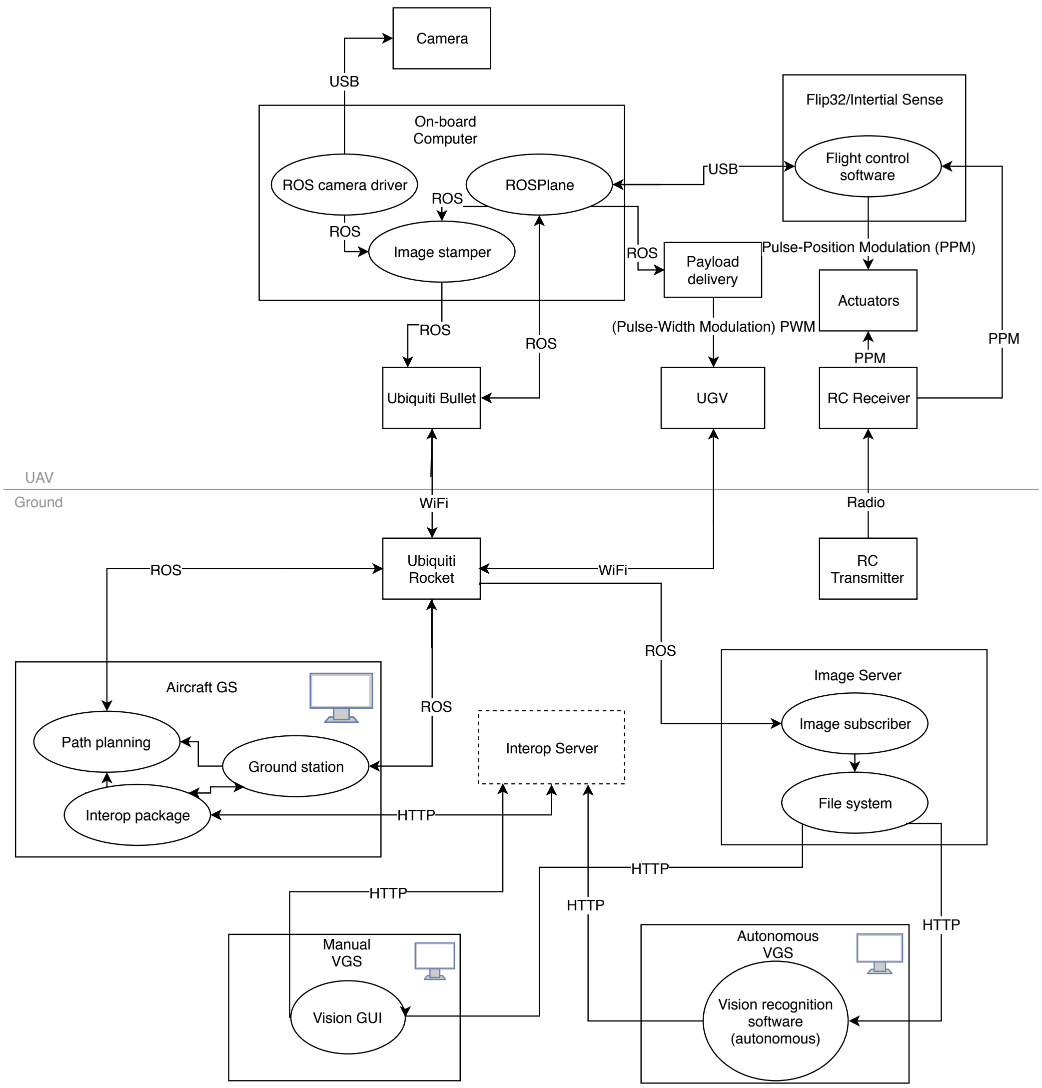

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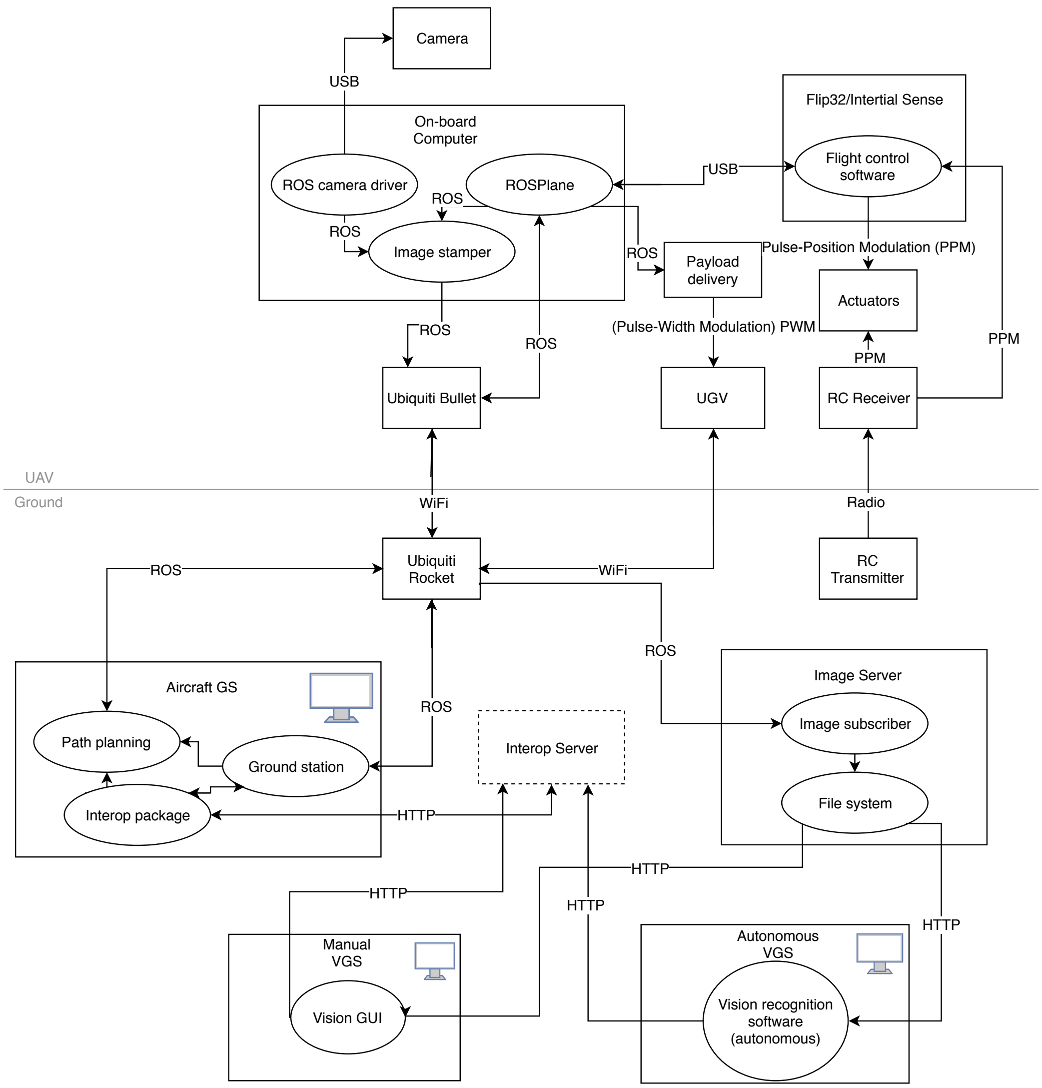

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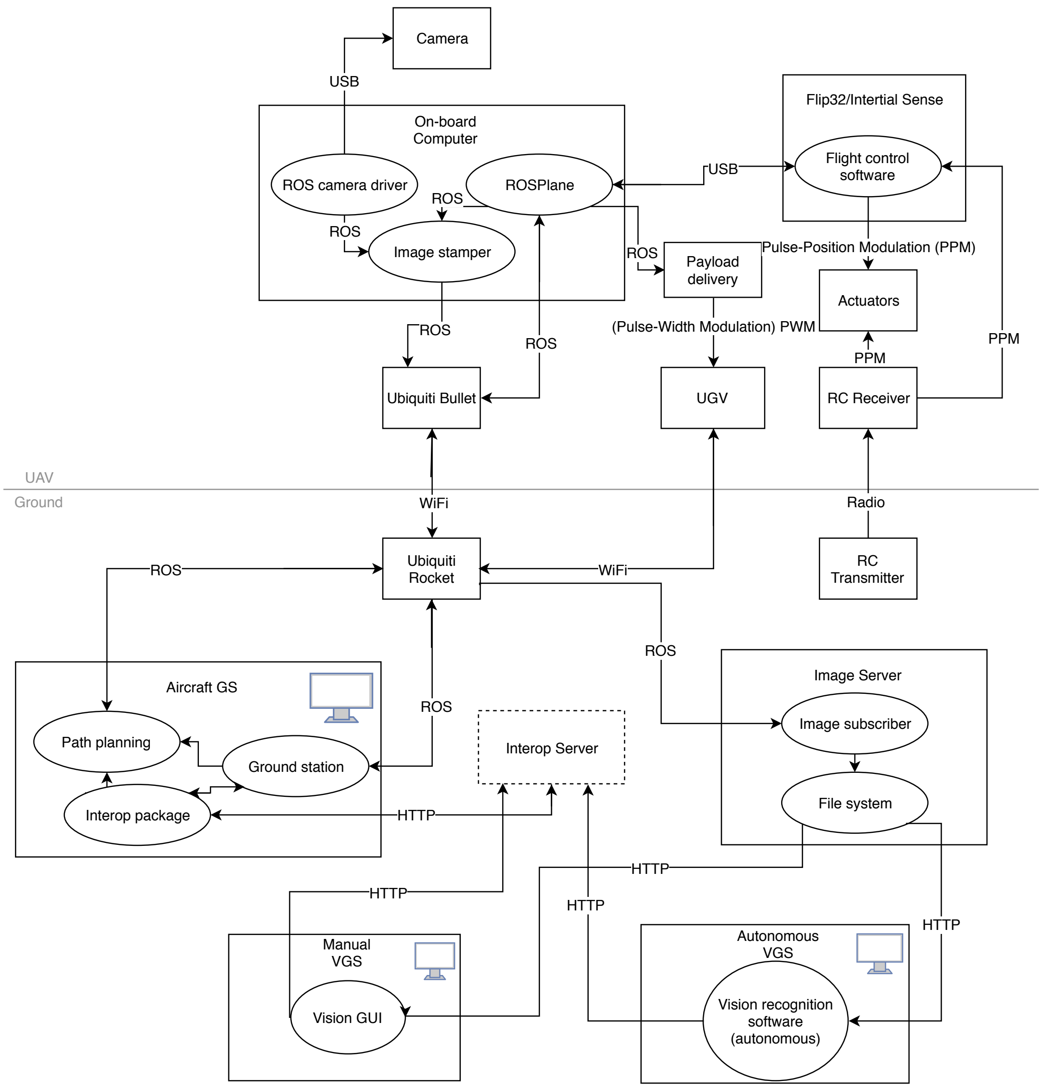

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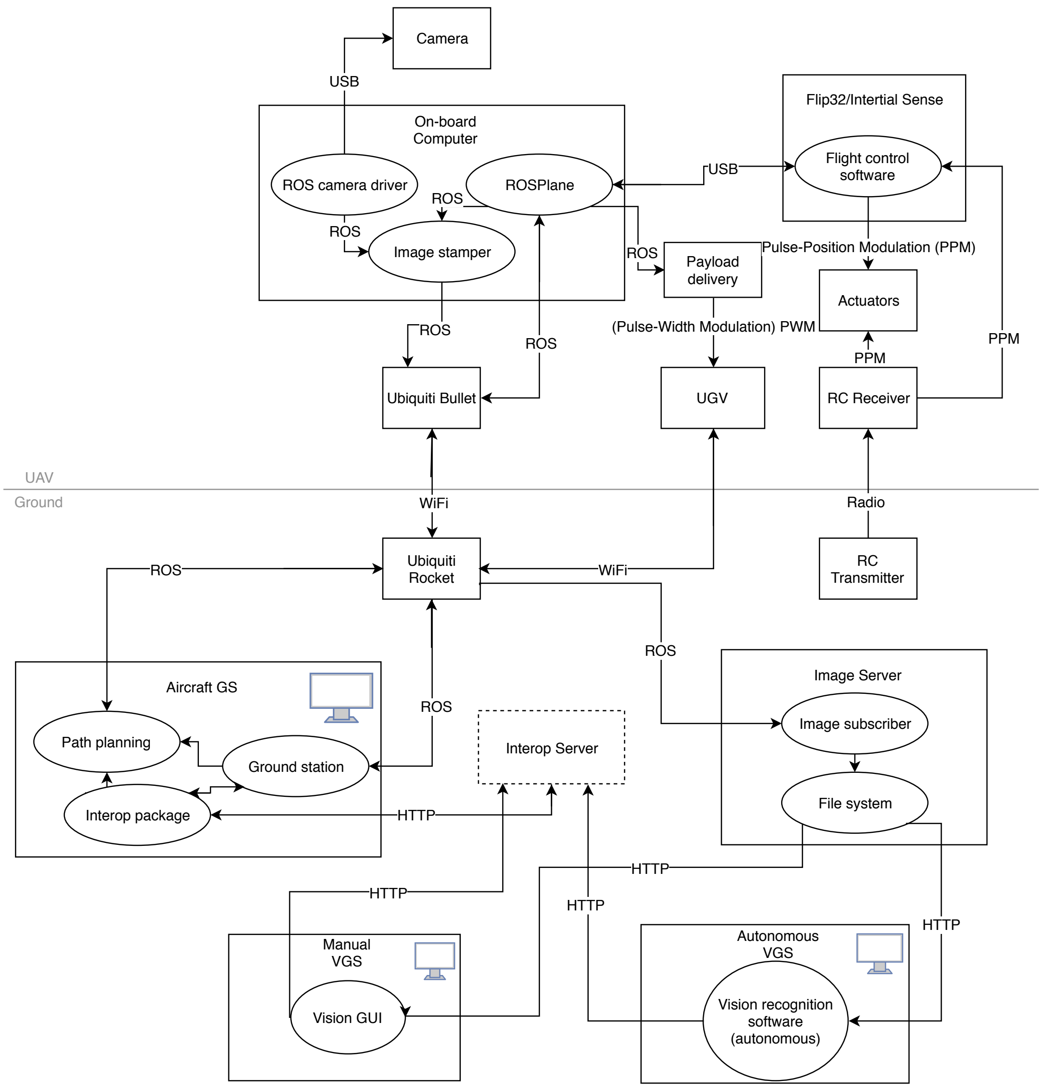

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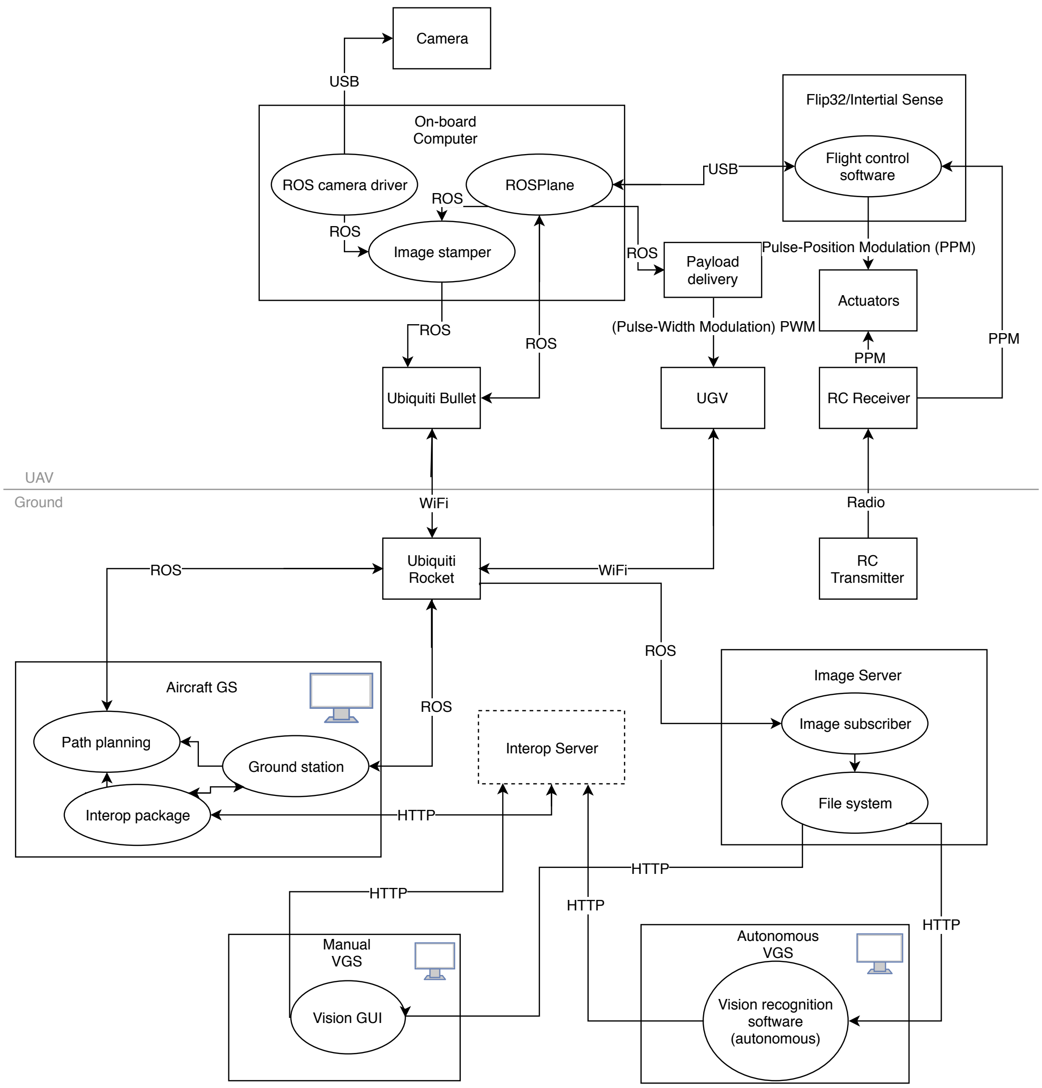

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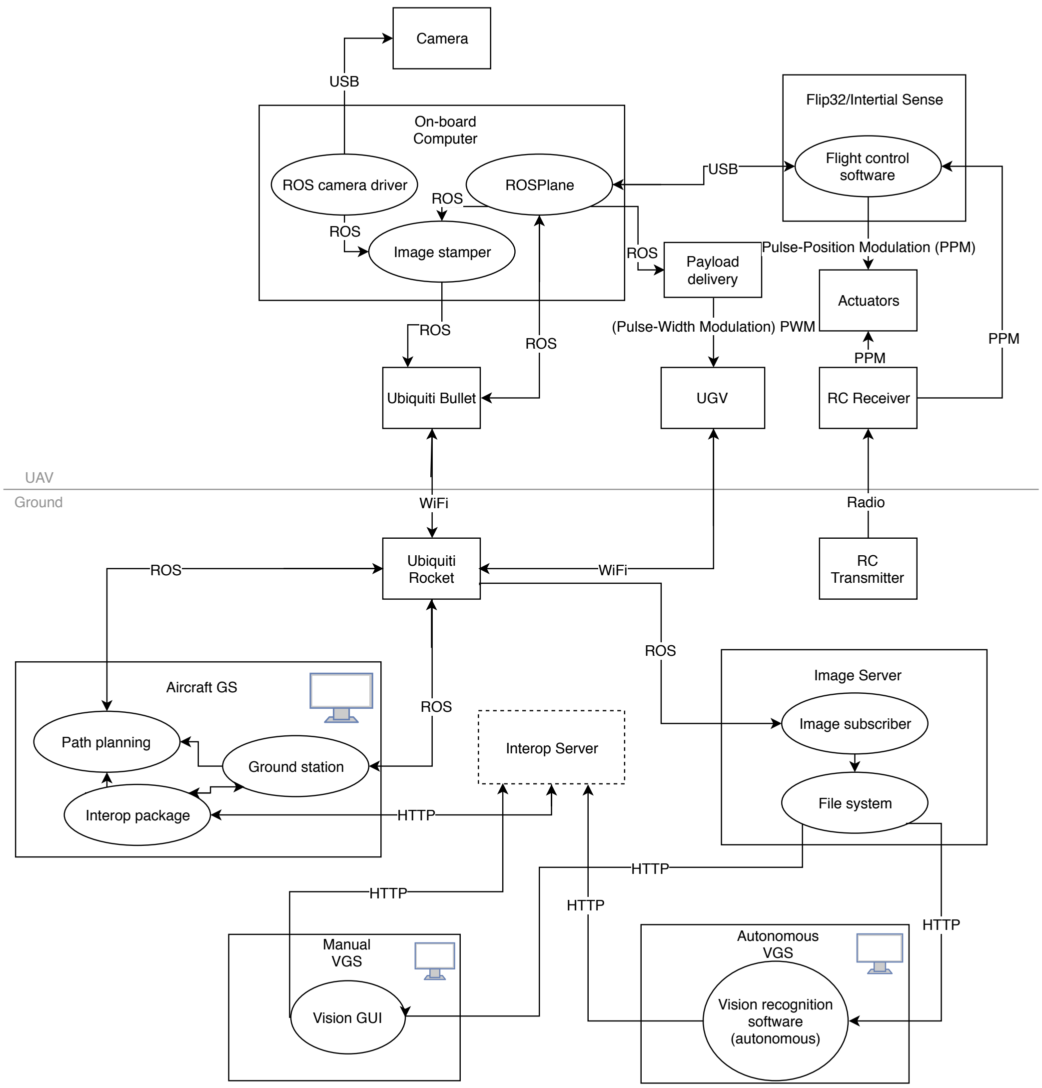

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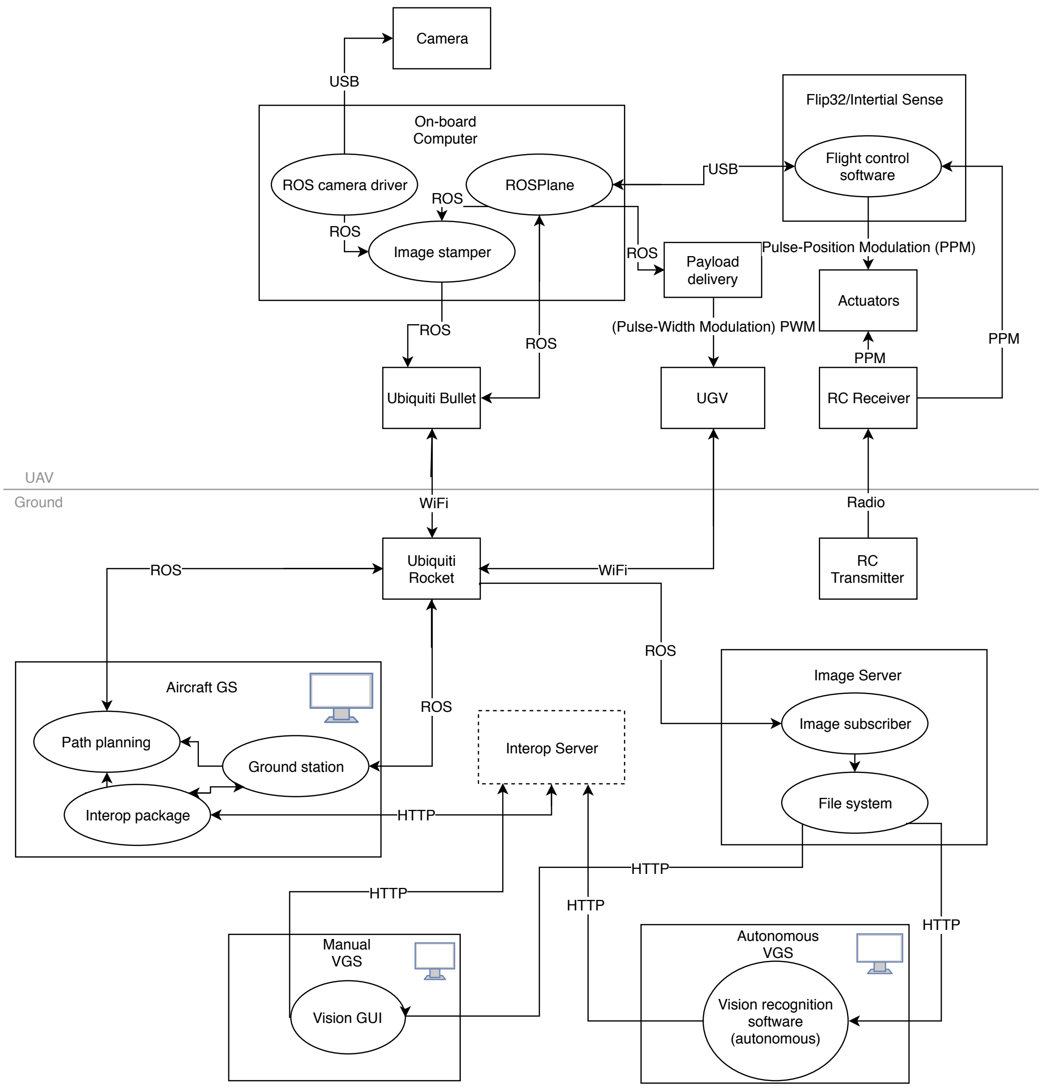

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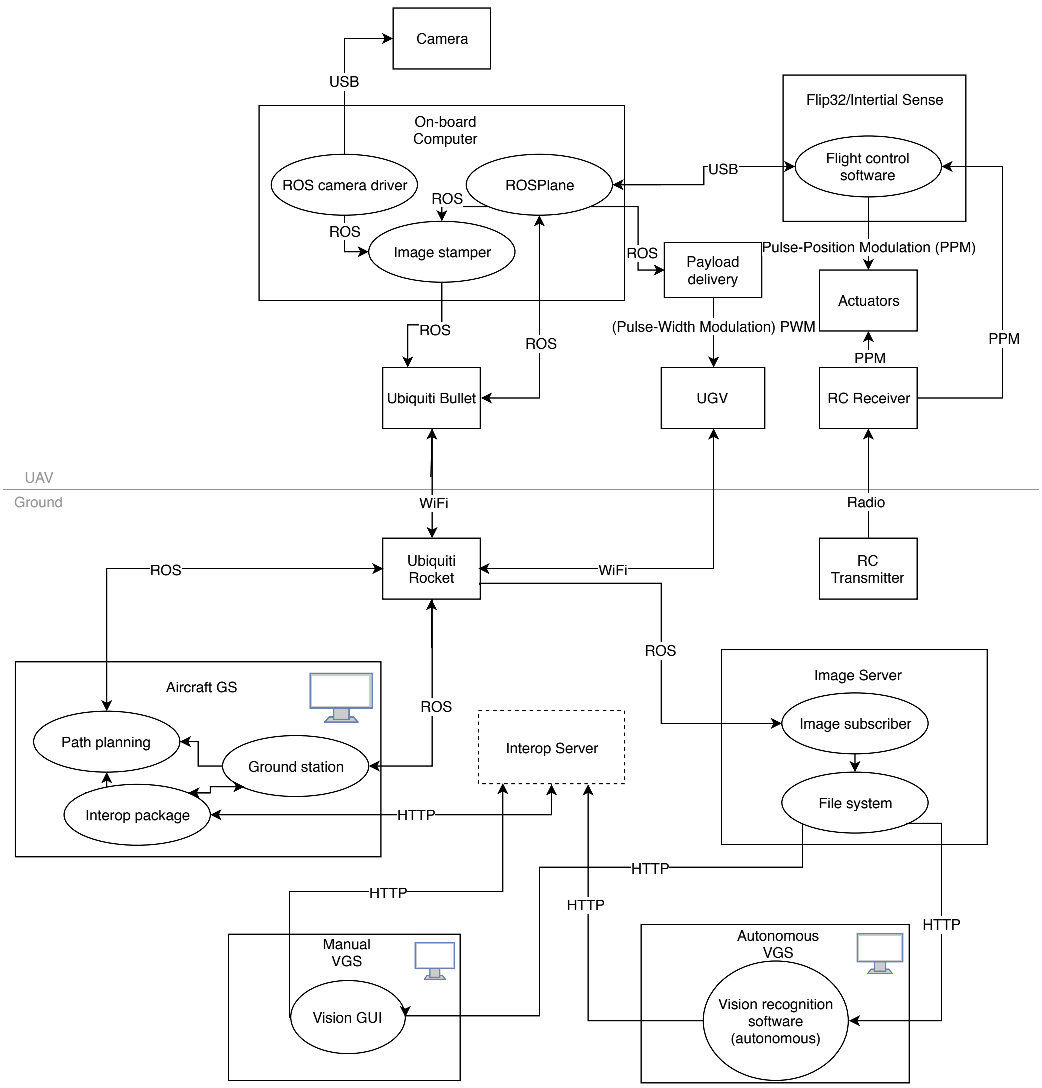

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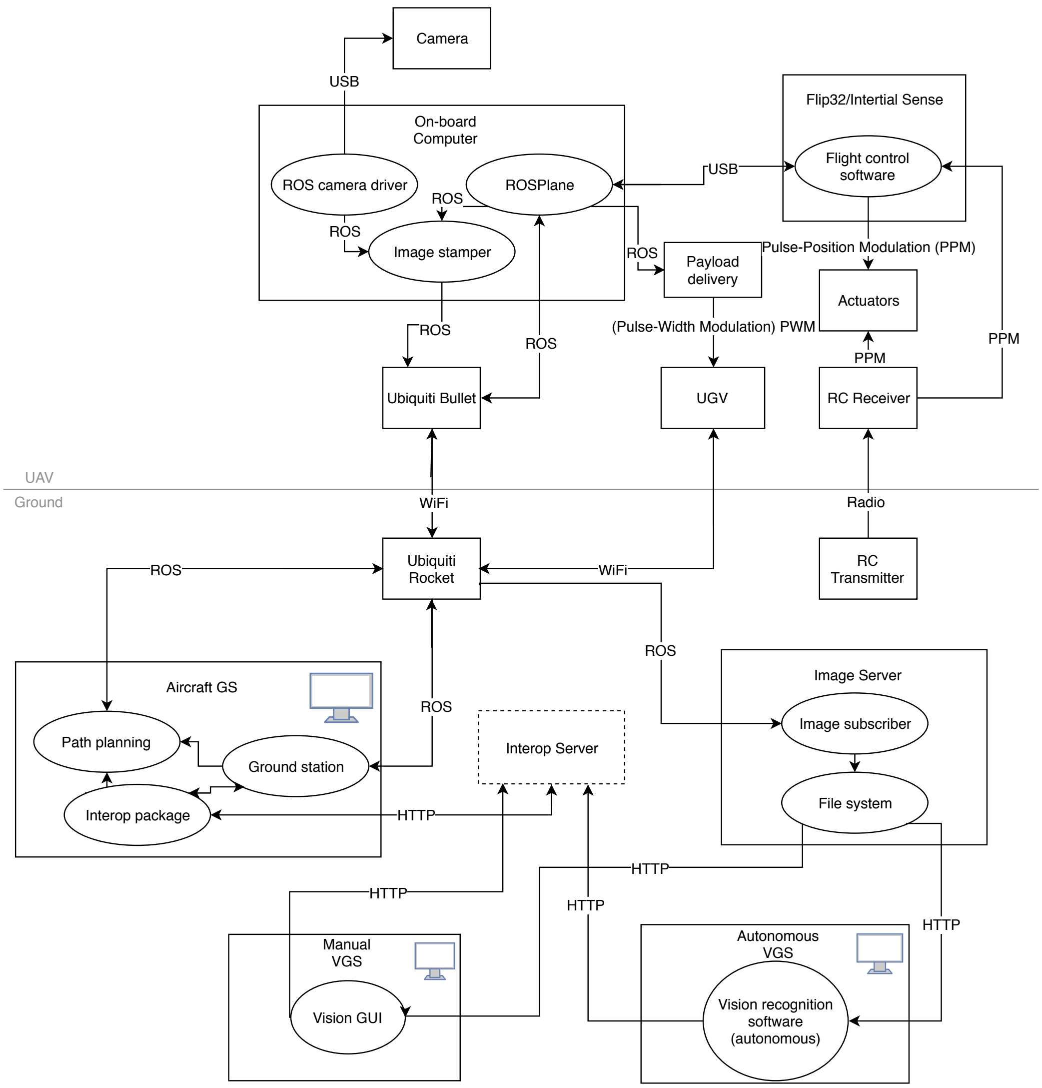

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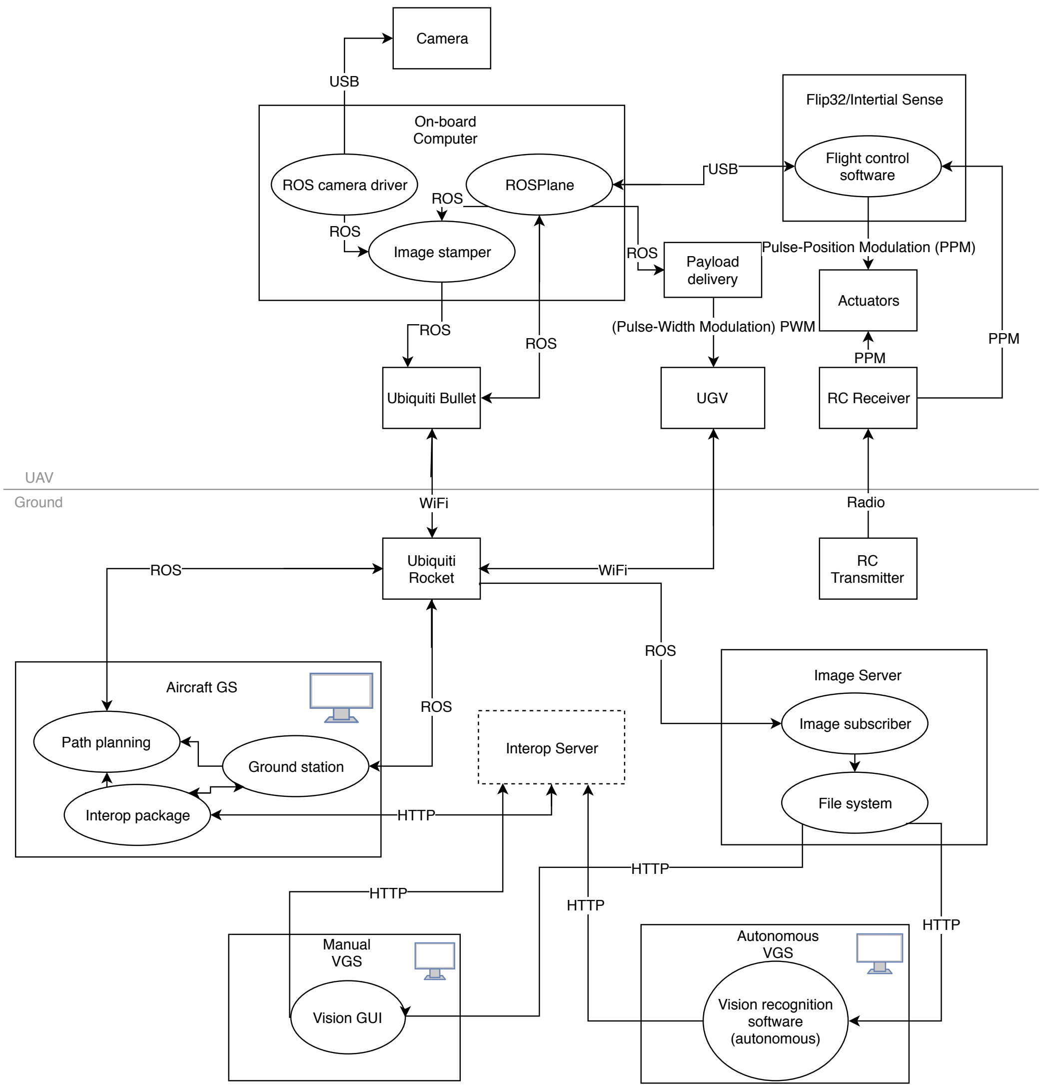

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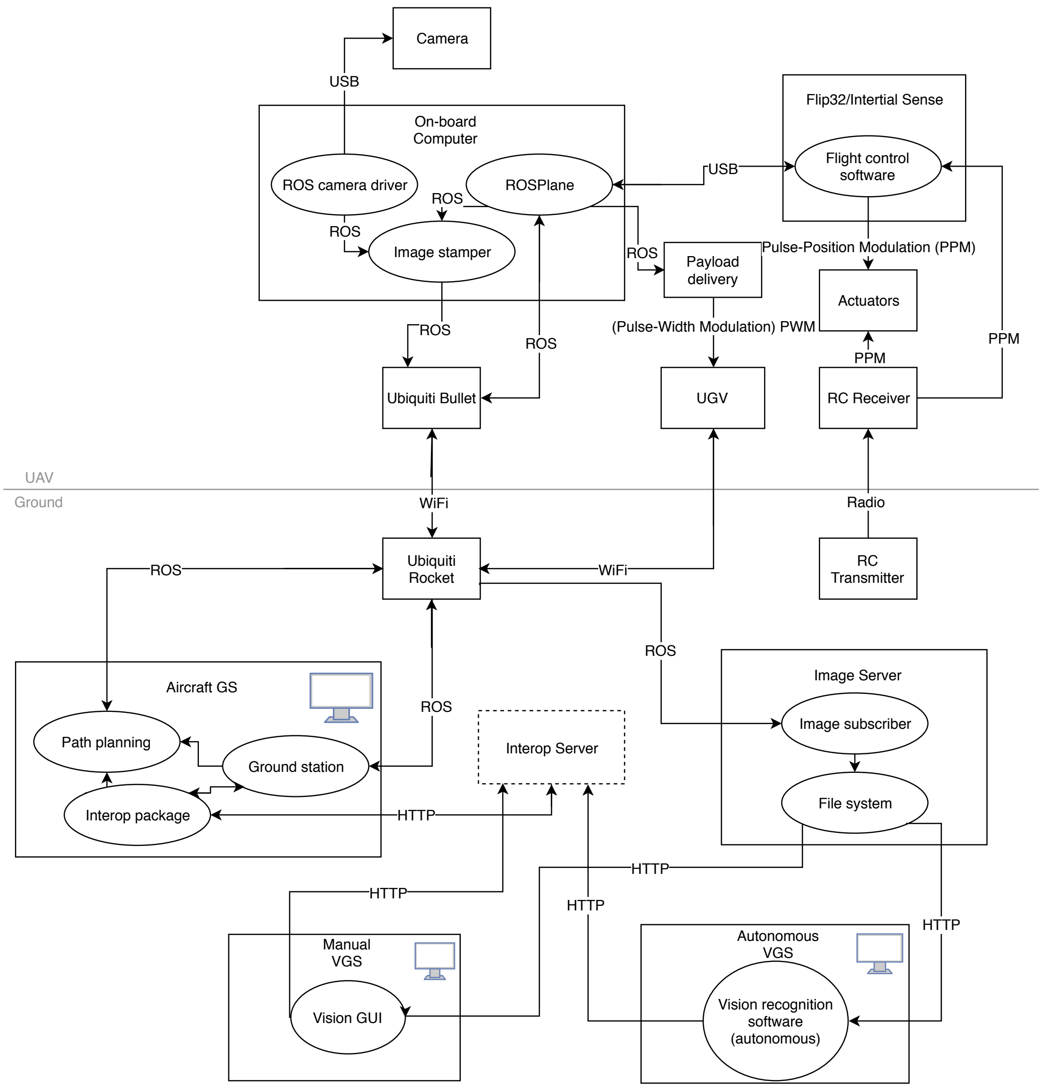

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Brigham Young University

AUVSI Capstone Team (Team 45)

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.

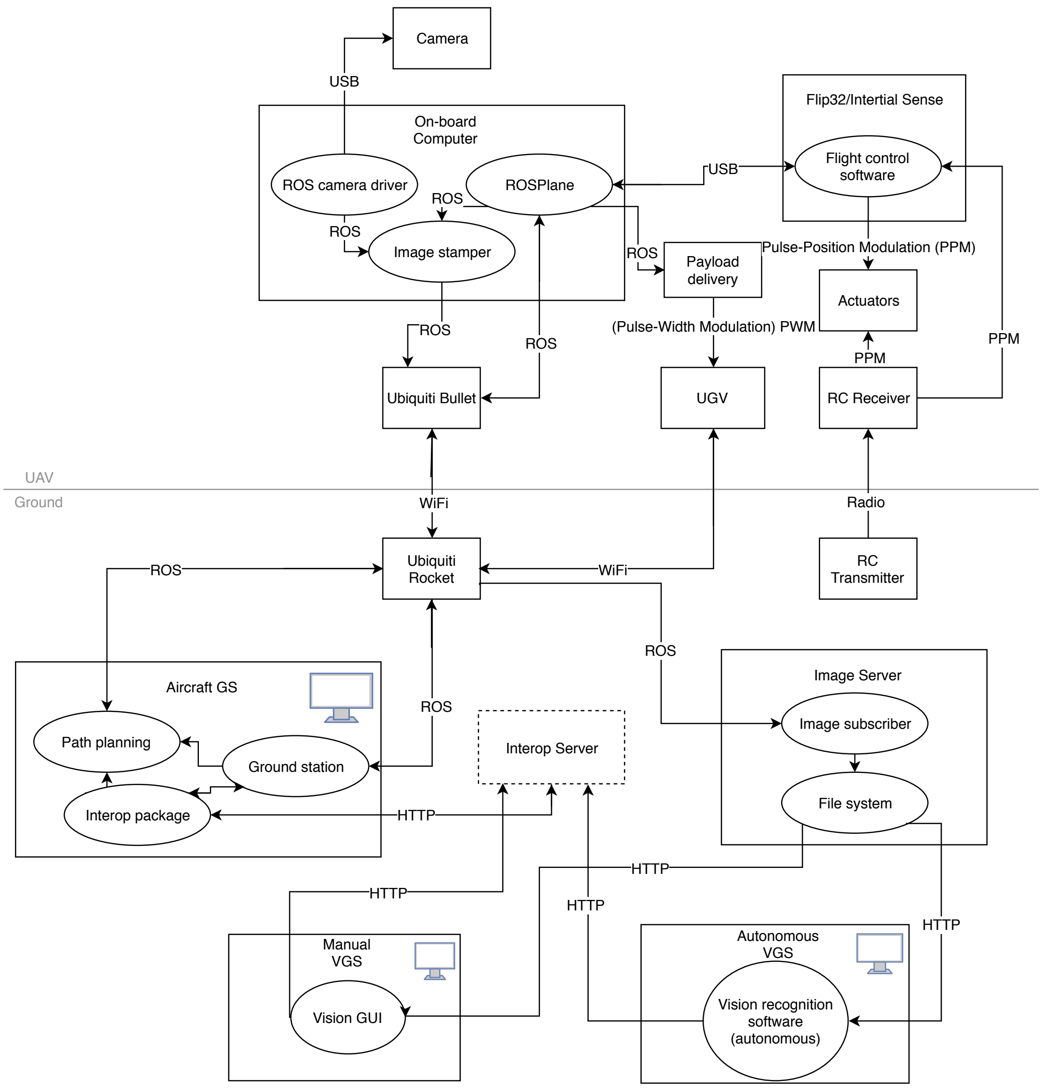

Figure 1: System-wide interface diagram for the UAS. Hardware is denoted by a box, and software is denoted by an oval.

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

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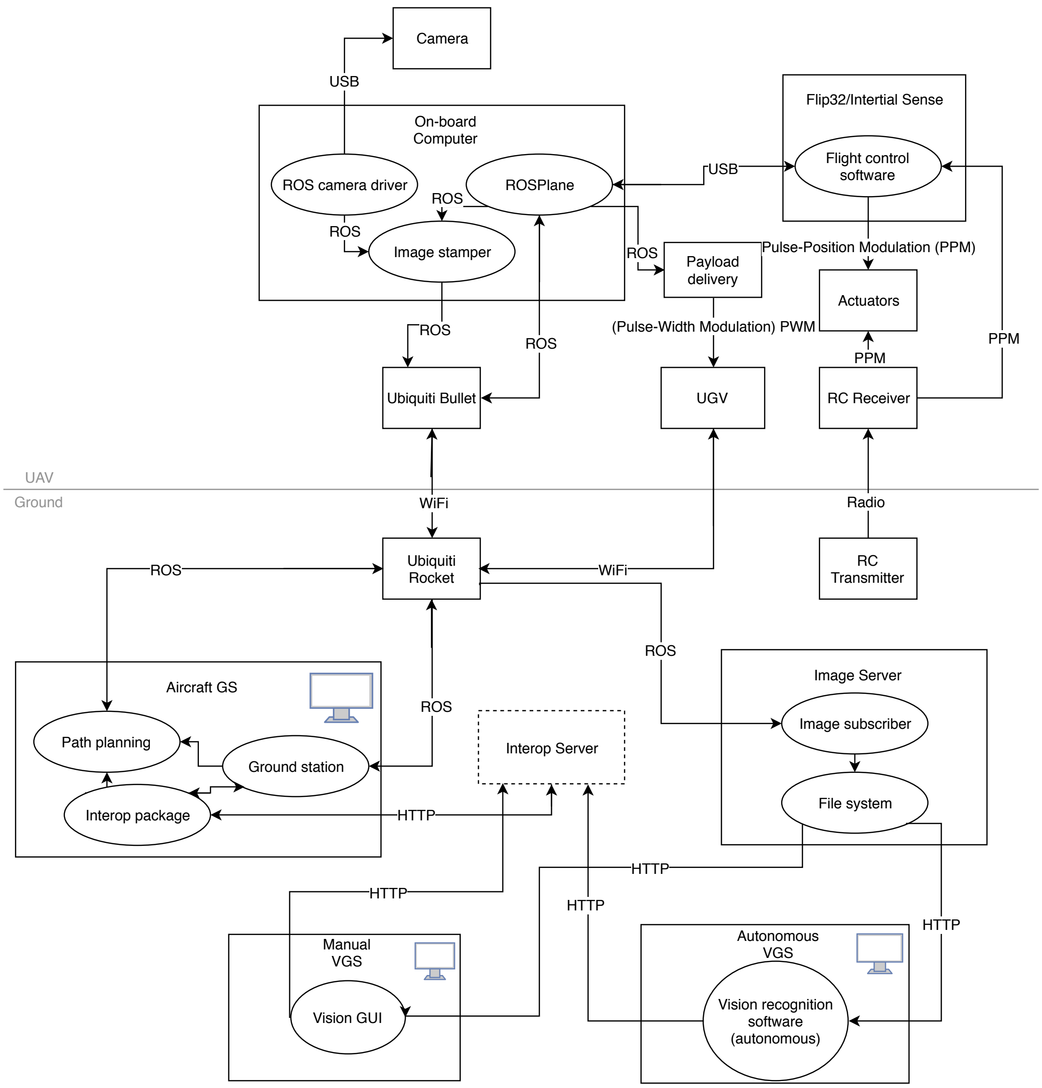

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