University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

RiBBIT

River **B**athymetry **B**ased **I**ntegrated **T**echnology

Approvals

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3. Problem or Need

Rivers are a critical resource to monitor due to their contributions to agriculture, urban development, hazard monitoring, and environmental monitoring. As global warming persists, the water cycle is a key indicator to track as it links the atmospheric, terrestrial, and oceanic processes [1]. One vital measurement to effectively track this resource is river discharge, or the units of volume per unit time. To calculate this, the river cross-sectional area must be multiplied by the river's velocity [2]. This measurement enables the amount of water available for human consumption or risk mitigation to be quantified. Currently, there is a lack of updated and accurate global data for river discharge, especially in hard-to-access environments. Existing Earth-orbiting satellites simply do not provide the accuracy and precision that in-situ, and UAV-mounted systems can enable [8].

To collect these river measurements, scientists from the United States Geological Survey (USGS) travel the world to collect in-situ river measurements. In the past, these measurements have been collected utilizing a tagline system, pulling a boat across the water with an acoustic depth-sensing instrument and velocity tracker [2]. Alternatively, helicopters towing radar systems have been utilized. However, both of these methods have proven to be expensive and dangerous in certain environments. To solve this problem, a river surveying device shall be designed to enable maximum science output for a portion of the cost of traditional methods.

In correspondence with Steve Nerem, Toby Minear, Jeff Thayer, and the Ann and H.J. Smead Aerospace Engineering Sciences department at CU Boulder, this team shall design, manufacture, and test a sensor system to gather river depth profile and velocity data in hard-to-access areas for the purpose of monitoring river discharge.

4. Previous Work

A number of local-scale LiDAR and echo-sounding technologies have been previously developed for underwater depth measuring. In addition to these local-scale systems, a number of Earth orbiting satellites have mission objectives of measuring the global hydrological cycle. However, those existing now do not have the capacity of capturing both highly accurate bathymetric data and streamflow in order to measure river discharge.

A French geomatic innovation and technology company called Hélicéo designed a LiDAR laser system, named Puma32, that is capable of 3D mapping to a depth of 200m underwater. The weight of Puma32 is 1.8 kg and it can successfully make the measurements within an accuracy of no more than ±3cm [3]. Another Australian company called CEE Hydrosystems developed an echo sounder system with a similar depth range capability but higher precision measurements. This echosounder system is called CEE Echo and is accurate up to ±1cm [4]. In addition, a European company called Universal Ground and Control Software (UGCS) developed a deployable echosounder, ECT 400, that is unique for its lightweight and high precision capability that can be as accurate as ±1mm [5].

Additionally, NASA has an upcoming launch for the Surface Water and Ocean Topography (SWOT) mission which is "...focused on a better understanding of the worlds oceans and its terrestrial surface water." To date there have been 256 scientific publications related to the missions anticipated applications and calibration and validation of its instruments among other things. There has also been a mission called AirSWOT using a Beechcraft Super King Air B200 Aircraft for support of SWOT. It performs water elevation mapping, surface characterization and classification, signals attenuation by vegetation and validation of water discharge algorithms [10].

Another space-based water monitoring mission is Jason-3 that is operated by NASA and launched early 2016. Jason-3 is utilized for a variety of both scientific as well as commercial applications including monitoring water rise, ocean circulation and climate change. According to NOAA “Jason-3 will make highly detailed measurements of sea surface height, which is a measure used to study sea level rise—a critical factor in understanding Earth’s dynamic climate."[6]

5. Specific Objectives

Table 1 outlines the levels of success for the project with Level 1 outlining the minimum requirements for mission success. Further development of mission components is presented in Level 2. Level 3 includes the ideal image of what this project can accomplish upon completion.

Turbidity is a major factor in a LiDAR system’s performance and needs to be quantified for proper testing. For this project the turbidity will be measured in Nephelometric Turbidity Units (NTU) where a visualization is provided below.

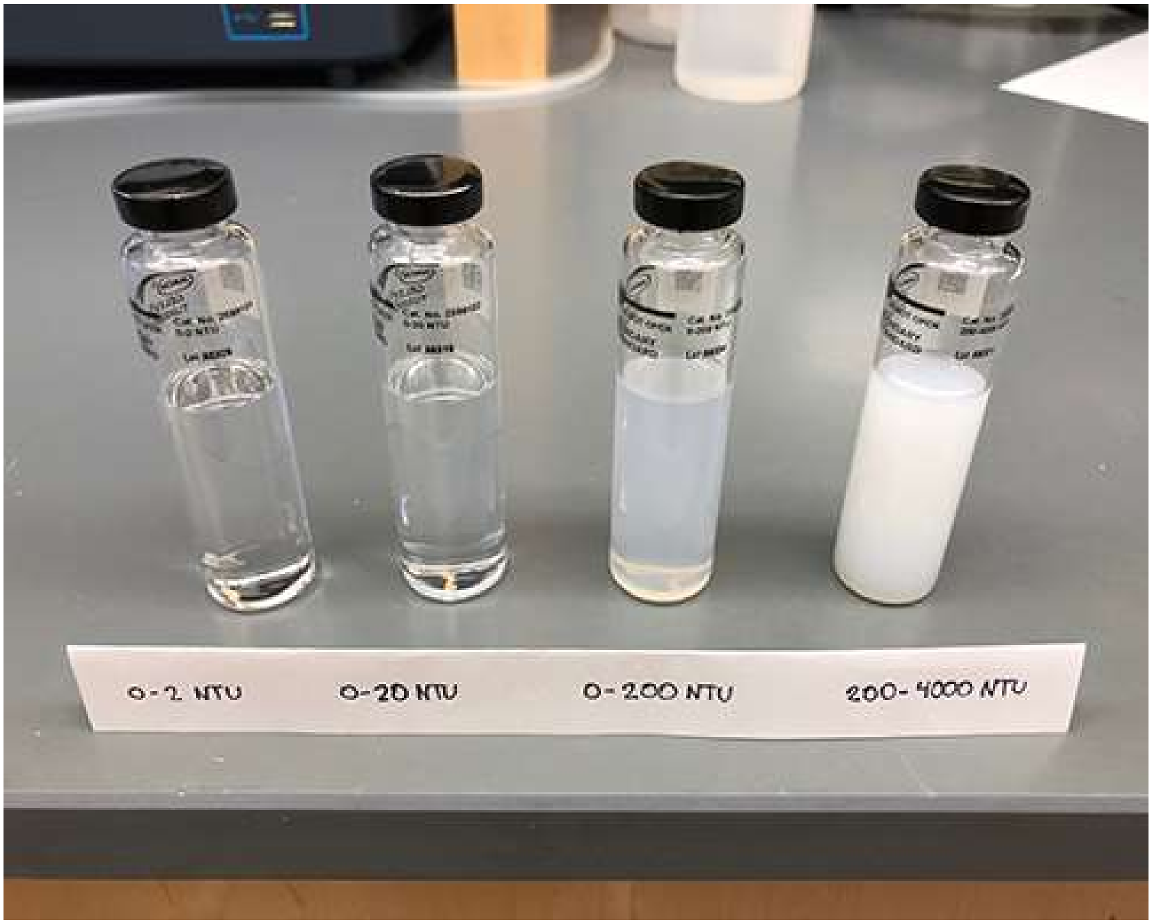

Figure 1: Turbidity Visualization [11]

Table 1: Levels of Success

	Level 1	**Level 2**	**Level 3**
Bathymetric Measurements	• System can measure river depths to 3m in water with less than 10NTU and an accuracy of TBD.	• System can measure river depths to 5m in water with less than 10NTU and an accuracy of TBD. • System can measure river depths to 3m in water that has up to 25NTU.	• System can measure river depths to 7m in water with less than 10NTU and an accuracy of TBD. • System can measure river depths to 5m in water that has up to 25NTU. • System can measure river depths to 3m in water that has up to 50NTU.
Streamflow Measurements	• System can measure streamflow in slow moving waters with TBD accuracy.	• System can measure streamflow in moderate moving waters with TBD accuracy.	• System can measure streamflow in rapidly moving waters with TBD accuracy.
UAV Positional Measurements	• Default positional data from off-the-shelf drone	• Higher accuracy positional data from additional GPS receivers	
Data Handling	• All measurement data is stored in on-board memory.	• Signal to user indicating data acquisition has begun.	• Data stream to user during data acquisition.
Drone Command & Control	• Drone is capable of being flown manually the entire course of the flight.	• Drone is capable of being flown manually the entire flight with commands to correct for wind or other disturbances.	• Drone is capable of autopilot and will fly along a preprogrammed flight path.

Table 2: Levels of Success

	Level 1	**Level 2**	**Level 3**
Operating Environments	• Drone can navigate environments with minimal wind TBD.	• Drone can navigate environments with small obstacles such as trees and boulders. • Drone can navigate environments with slight wind TBD.	• Drone will operate in environments with obstructed (TBD) flight path.
Power	• All on-board sensors shall be powered at minimum for the flight duration of 720 seconds.	• All on-board sensors shall be powered for 720 seconds with reserve charge.	• Drone shall be able to draw upon reserve sensor suite power under necessary conditions.
Data Verification and Validation	• River velocity and depth profile data shall be compared to in-situ measurements to observe system accuracy.	• Depth profile data shall be compared to that collected by AstraLite.	• Ground control points shall be collected and integrated into the depth profile model to ensure the model is accurately georeferenced (exact accuracy TBD).
System Testing	• Perform unit tests of all individual sensor components.	• Perform test with integrated sensor components	• Perform integrated drone-sensor system test.

6. High Level Functional Requirements

6.1 Functional Requirements

The following outlines the high level functional requirements that were derived from the project objectives. These functional requirements will be the basis of the requirement flow down, steer what trade studies will be conducted, and inform the testing to be completed. Additionally listed is the motivation behind the requirement as well as the flow down consideration for further design requirements.

FR1. RiBBIT shall be a transportable unmanned aerial vehicle system.

Motivation: This comes from the need that the system must be able to travel to various locations via car, helicopter, plane, on-foot.
Flow down consideration: Weight, size

FR2. RiBBIT shall be composed of commercial off the shelf components.

Motivation: This is derived from the project's problem space as many river discharge/bathymetry surveys are significantly expensive. RiBBIT's goal is to get roughly 90% of the data from these top-of-the-art systems at relatively low cost.
Flow down consideration: N/A

FR3. RiBBIT shall be able to operate in difficult to access river locations.

Motivation: This requirement is founded on the fact that many rivers are in private or difficult to access locations for typical survey campaigns. The goal of this system is to make it easier to survey these types of locations.
Flow down consideration: Drone command and control, flight time, environmental condition

FR4. RiBBIT shall measure the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.

Motivation: In order to measure river discharge, RiBBIT must profile the cross section of the river by measuring water surface level, width, and river depth perpendicular to the current.
Flow down consideration: max depth in clear water, accuracy

FR5. RiBBIT shall measure the streamflow of a river.

Motivation: In order to measure river discharge, RiBBIT must measure the flow rate of the water.
Flow down consideration: max river velocity, type of velocity (surface velocity, below surface), accuracy

6.2 Concept of Operations (CONOPS)

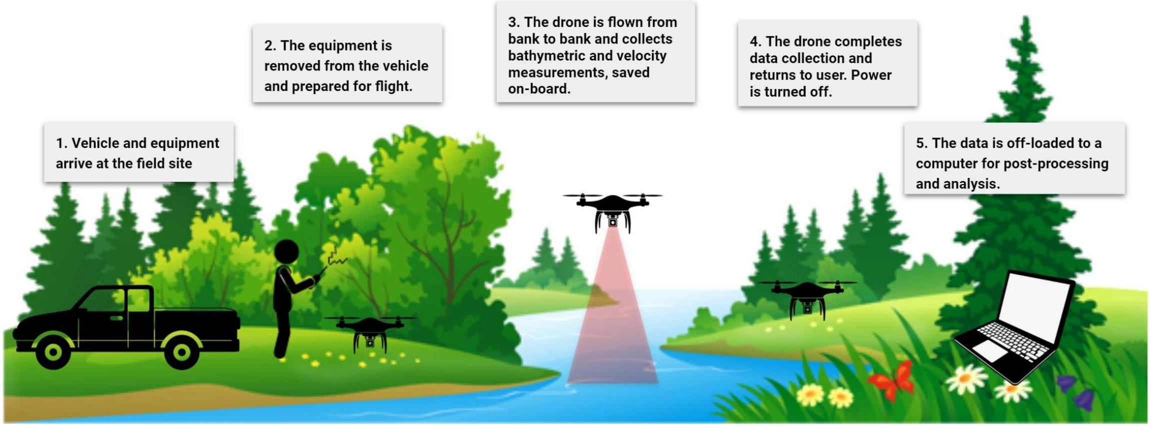

Figure 2: RiBBIT Concept of Operations

The purpose of this mission is to provide a low-cost, light, and long-range drone with mounted sensors to enable river discharge and bathymetric data collection. Figure 2 shows the expected mission procedures of the RiBBIT system. The mission begins with a set-up period where the vehicle and equipment arrive at the river site. The drone and sensor system are then prepared for flight by qualified personnel. The drone shall be elevated to TBD altitude and flown from riverbank to riverbank, perpendicular to the stream flow. While in flight, the sensor package shall collect river discharge and bathymetric data. The collected data will be saved on-board. Once the system has completed the data collection phase, the drone will be flown back to the user, and the system will be powered off. After the data collection has been conducted, the data shall be off-loaded to a computer. Post-processing of the data shall be carried out to ensure the data is in the format necessary for customer use.

7. Critical Project Elements

7.1 On-Board Instruments/Sensors

The collection of river depth data is crucial to the success of this project and will be completed through the use of either an aerial 532 nano meter LIDAR sensor or a float mounted echo sounder sitting on the water's surface trailing behind the aerial platform. The system shall be able to measure a depth ranging from 0.2 to 10 meters with an accuracy of 1 percent. The senor package shall also be able to measure the flow rate of the river using either an optical system attached to the the aerial platform or a river level flow rate sensor attached to the trailing sensor float. These design requirements will pose a challenge in our trade studies, the selection of a sensor will have a major effect on the weight and methods of operation.

7.2 Flight Vehicle

The flight vehicle shall be a battery powered multi rotor platform that is able to lift the sensor package and have a minimum hover time of 720 seconds (12 minutes). The flight vehicle being able to lift the sensor package and maintain the desired flight duration is critical in the clarity of the data. The hover time requirement is derived from USGS data collection guidelines [2].

7.3 Ground Systems

The ground systems shall be composed of a drone pilot and RC controller as well as a computer to offload the collected data. Additionally, a GPS or GNSS receiver may be included to collect ground control points to ensure accurately georeferenced models. Without a well developed ground system the data can become either unusable or very difficult to offload and handle.

7.4 Command & Data Handling

The aerial platform shall be able to be controlled remotely by a pilot on the ground using a wireless four or more channel remote control. The data collected by the sensor package shall be easily accessible and transferable to a local computer for processing.

7.5 Integration & Testing

Access to a pool, pond, river, or lake shall be necessary in order to perform instrument tests and a final test of the fully integrated system. The testing will present a challenge due to flight restrictions around the nearest bodies of water and it shall also require good weather and good surface conditions for initial testing.

7.6 Software

A software package shall be developed that integrates all the provided software from the instruments and flight vehicle. Post-processing software shall also be utilized after data collection. If a software package isn't developed properly a good data set can end up being useless; due to software serving as the link between individual components, creating the final sensor package.

7.7 Safety & Regulations

The flight vehicle shall be controlled by an FAA Certified Drone Pilot. The unmanned aircraft shall remain in the visual line-of-sight of the pilot. The aircraft will only operate under daylight or within civil twilight. Civil twilight refers to the time 30 minutes before the official sunrise time to 30 minutes after the official sunrise time for the specific location. If there are any additional unmanned vehicles operation within the same space, the aircraft must yield to the right of way of the other. The ground-speed will not exceed 87 knots, or 100 mph. While in operation, the aircraft cannot exceed 400 feet above the ground level with a minimum visibility of 3 miles from the controller. This aircraft will not contain or store any hazardous materials. A pre-flight inspection must occur before the aircraft is deployed. If these requirements are not followed no flights can be performed and no testing can be done.

8. Team Skills and Interests

Table 3: Team Skills and Interests

Team Member	Skills/Interests	CPEs
Phil Miceli	Main skills are software related, including extensive work with MATLAB and Simulink, C++, C, MySQL, and Git. Also have experience in requirement writing and working in DOORS (Dynamic Object Oriented Requirements System). Main interests include designing control systems and flight software development.	7.2, 7.5, 7.6
Megan Jones	Data Post-Processing Software (Agisoft, Pix4D, Meshlab), Drone build/flying, MATLAB, Python, C++, Java. Interested in systems engineering and scientific/research applications to aerospace technologies. Also drone build and sensor system integration.	7.1, 7.2, 7.3, 7.5, 7.6
Mikaela Dobbin	Skills in Simulation building in Python and MATLAB. Object Oriented Programming and software development primarily in Python and C++. Main interests in data processing, GPS, navigation, and estimation.	7.1, 7.2, 7.5, 7.6
Paul Andler	Experienced with Matlab, Python and some C++ as well as Fusion 360. Also experienced with building and flying multi-rotor platforms. Mainly interested in software development and hardware design.	7.1, 7.2, 7.5, 7.6
Daniel Crook	Software engineering: Python, C++, ROS, Gazebo, MATLAB, Linux. Currently focused on formal verification and reliable autonomous systems.	7.1, 7.3, 7.4, 7.6
Samuel Razumovskiy	Experienced with Modeling software (SOLIDWORKS, AutoCAD), programming (MATLAB, Python, C++), Linux/Ubuntu systems. Interested in drone-instrument software and hardware interface.	7.1, 7.2, 7.5, 7.6
Jessica Knoblock	Experience with software development and IV&V testing. Skills with Python, C++, MATLAB, Linux, and some C. Mainly interested in software development and interpreting the gathered data in order to provide results that are meaningful to the science objectives.	7.1, 7.4, 7.5, 7.6
Courtney Gilliam	Experience with communications, budgeting, negotiation, materials, import processes, and MATLAB. Interested in: manufacturing processes, along with research and design.	7.7
Abdullah Almugairin	Skills in post processing data in MATLAB and some experience with C++. Experience with using the laser cutting machine. Interested in flying the drone and manufacturing parts needed.	7.2, 7.5, 7.6 7.7
Andrew Benham	Experience in Solidworks, MatLab, Science Communication, Science Policy. Interests in aerospace and climate change research, regulations, manufacturing and leadership.	7.1, 7.2, 7.3

9. Resources

Table 4: Resources

Critical Project Elements	**Resource/Source**
On-Board Instruments	Professor Thayer, Toby Minear
Flight Vehicle	Professor Thayer, Dan Hesselius, Research and Engineering Center for Unmanned Vehicles (RECUV)
Ground Systems	Professor Nerem, Professor Morton
Command & Data Handling	Research and Engineering Center for Unmanned Vehicles (RECUV)
Integration & Testing	Bobby Hodgkinson, ASPEN Flight Space, Integrated Remote and In-Situ Sensing (IRISS) Lab
Software	Research and Engineering Center for Unmanned Vehicles (RECUV)
Safety & Regulations	Dan Hesselius, Matt Rhode, Bobby Hodgkinson

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