DESIGN CONSIDERATIONS FOR RIVER FLOATING SENSORS

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Abstract

In order to utilize the flow of a river to generate power, it is crucial to develop a system that is able to obtain and record the river's characteristics in various aspects. A simple but effective method has to be created to allow researchers to collect and study the parameters of a river in order to predetermine the final build of the power generation model. A floating sensor that is able to collect and give a real-time data has been developed using readily available hardware as well as custom made parts. This paper describes a design methodology for river floating sensors and results from a case study performed in the actual controlled channel are presented to demonstrate the effectiveness of the design decisions.

Keywords: Data assimilation, Mobile sensors, River flow, Sensor network

Introduction

The demand for human freshwater that available through rivers will increase significantly in the next few years, due mainly to widely use of water intensive agriculture and increment of population and urbanization [1]. On the other hand, clean and renewable electricity generated from nearby river can be provided to communities and cities using hydrokinetic technologies [2]. In order to improve the efficiency of freshwater usage, a proper monitoring process using recent mobile sensing technologies is highly required. One of the examples of environmental management situations requiring understanding of complex hydrodynamic systems includes predicting the impact of the deployment of hydrokinetic devices on the flow, water level, and sediment transport. A high quality hydrodynamic model including the parameters of the river's kinematics will help to determine the optimum points where power generators need to be installed and operated. Additionally, it can be essential for responsible environmental policy and decision-making.

The main properties of a riverine can be obtained using several different sensor types and modalities. Sensors are often classified as Eulerian or Lagrangian sensing: an Eulerian sensing is utilized when they observe the medium as it flows past a fixed location whereas the Lagrangian sensing are embedded into the flow itself, measuring the medium while moving along a watercourse [3]. The relative benefits of Lagrangian sensors compared to Eulerian sensors can be categorized into two types: *logistical* benefits and *information* benefits. The conventional Lagrangian sensor or *drifters* is a small floating package that transmits its location, and possibly other sensor measurements, as it is carried by the water current through the system. The Lagrangian system consists mainly of a microcontroller board, Global Positioning System (GPS) receiver and several sensors to collect raw data from the river. It would also have the capability to stream real-time data from the module to a control center and/or collect and store various river parameters relative with time and location which can be accessed later on for data analysis. The overall set up of the floating sensor is a waterproof floating hull that encloses an electronics package.

While most infrastructural sensing in rivers is implemented using Eulerian sensors, the evolution of wireless sensor network technology has increased the interest in novel Lagrangian sensor systems. However, the previous developments in wireless sensor networks for acoustic sensing are not suitable for Lagrangian sensing: required specialized equipments and non-symmetrical drag profile to the flow. This includes the Autonomous Modular Optical Underwater Robot (AMOUR) project in Massachusetts Institute of Technology (MIT) [4], the Slocum drifters at Monterey Bay Aquarium Research Institute (MBARI) [5] and smart sensor network in Galway Bay [6]. Recently, a system of robotic Lagrangian sensors was designed for the deployment in shallow water environments [3, 7, 8]. All these previous works are the foundation in which the core concept of the devices' operation has been emulated and tested.

This paper describes the design and implementation of a system for data gathering process of the river floating sensors. Moreover, this paper highlights the use of a design methodology inspired from Ishikawa 'cause and effect' framework [9]. This method would help to visually portray the potential causes for a specific problem or effect and particularly beneficial in a group setting for situations in which little quantitative data is available for analysis. Results from a case study performed in the actual controlled channel are presented to demonstrate the effectiveness of the design decisions. Finally, conclusions and future work recommendations are briefly presented in last section.

System Requirement

In river surveying, there are several factors that are vital, they are: (a) structure to attach current-meter; (b) medium to transmit and collect river data; (c) power source to operate surveying device [10]. The design of the floating sensor will tackle this challenge by incorporating the sensors, telecommunication module and the power source in a small vicinity of a partially floating hull. Due to the effectiveness of a household water filter unit sustaining water from leaking out, inversely, the water filter unit would be a suitable and cost effective means of creating hull that would keep water from seeping in.

Current velocity of a river is complex since the motion of water is not uniform throughout the channel due to varying degrees of friction exerted upon the water when it flows across its channel bed. The velocity pattern shown in Figure 1 is highest near the middle of the river just below the surface and lowest close to the banks and bottom which makes the selection of hull made from water filter canister which protrudes underwater is vindicated for the body to flow in the parallel velocity [11].

The floating sensors being developed will have the option to correct their position through a series of predefined waypoints without human input which will be the active version of the prototype or freely moving through the natural velocity pattern of a river's flow which is the passive version. In order to carry this task out, the active version needs to employ an effective and reliable control system. In this prototype, the control system consists of longitudinal control system and lateral control system provided by two thrusters. The floating sensors will be controlled by an IMU based board called Ardupilot Mega.

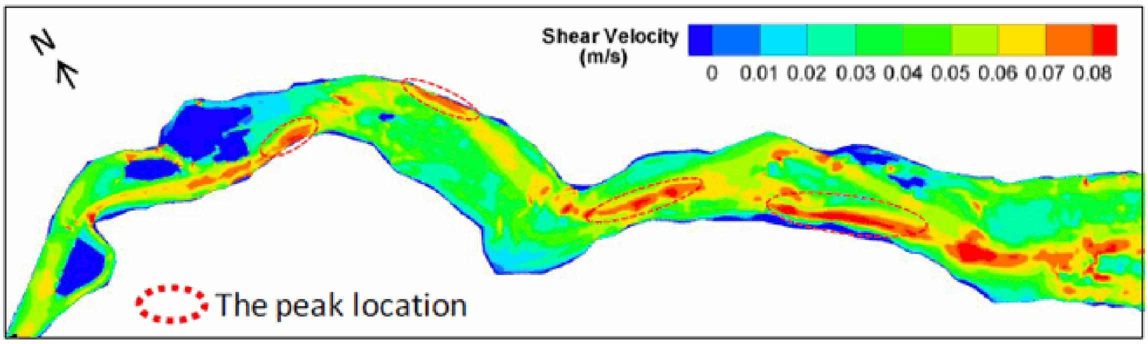


Figure 1. General current velocity patterns in rivers [11].

The prototype would utilize GPS, an accelerometer, and a gyrometer on the Ardupilot Mega to pin point its position and orientation in a surrounding. The system enables the user to go through a series of predefined waypoints using a simple cross track error trajectory. ArduPilot Mega can communicate with a ground station, where data can be gathered, waypoints, or even control gains can be updated. It communicates over a wireless serial connection, using a communication protocol. The attitude and heading reference system uses 3-axis gyro, accelerometer together with magnetometer. The IMU or inertial measurement unit of this board is based on micro-electromechanical system which is the MPU-6000 motion tracking device that combines three gyros together with three accelerometers.

Other crucial requirements are the expected functions of autonomous control algorithms from the board, primarily the throttle control and heading or yaw reference system, measuring of speed & acceleration, GPS behavior and on board voltage stability. The system should be capable of implementation of complex control laws and sensor fusion algorithms via Mission Planner software. Additional requirements include the identification and setup of the parameters to be uploaded to a firmware of the vehicle for test runs and data acquisition from the latter. For the passive version, the same Ardupilot Mega board is going to be used but with the exemption of the thrusters. This version will have the ability to transmit and record the kinematics parameters of a river referring to its natural motion in the respective river.

Design Methodology

In a design process, it is vital to take the required functional specification and producing a solution for the design limitation. Several design limitations needed to be considered which includes: (a) GPS and Telemetry modules should be exposed above water level to reduce signal loss; (b) Cylindrical shaped hull to hinder natural obstacles from clinging; (c) Low center of gravity to improve dynamic stability in water. To satisfy the limitations set, a design shown in Figure 3 is finalized for the active version and Figure 4 for passive version. While Figure 2 shows the actual prototype prior testing.

The microcontroller in the floating sensor which is the APM 2.5 should be able to record all the values of the sensors on board in relation to time. The IMU of the APM system will detect minute changes in yaw, position, and the acceleration of the body in order to calculate the errors and use the PID controller embedded in the system to recalculate its heading and give the appropriate PWM signals to the right and left motors where 32 mm propeller is rigged.

Figure 2. The finalized prototypes

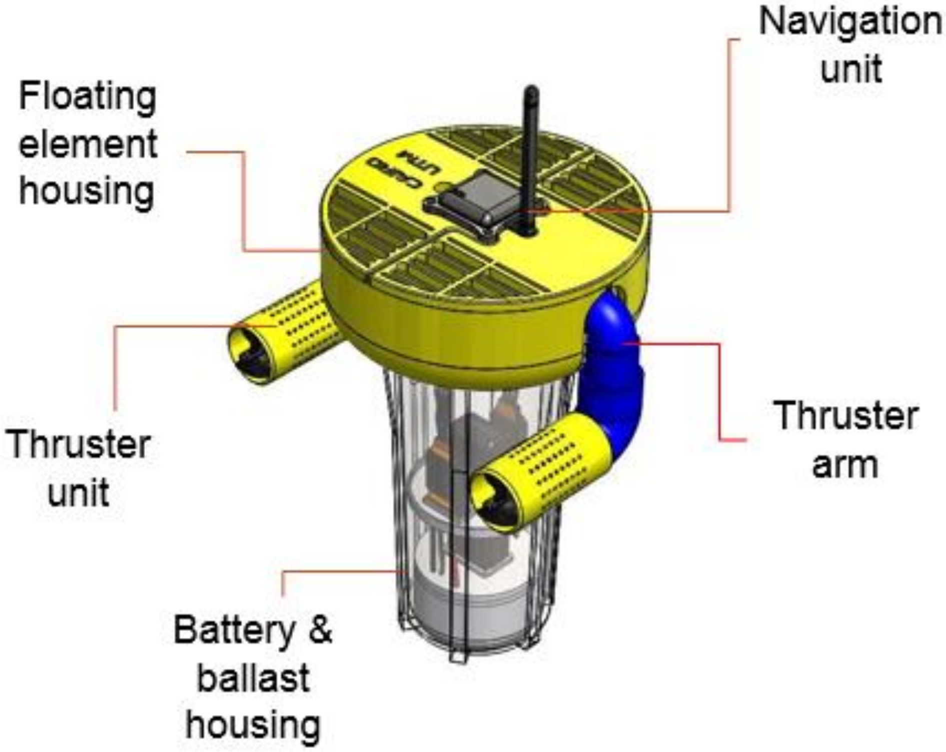


Figure 3. Active floating sensor

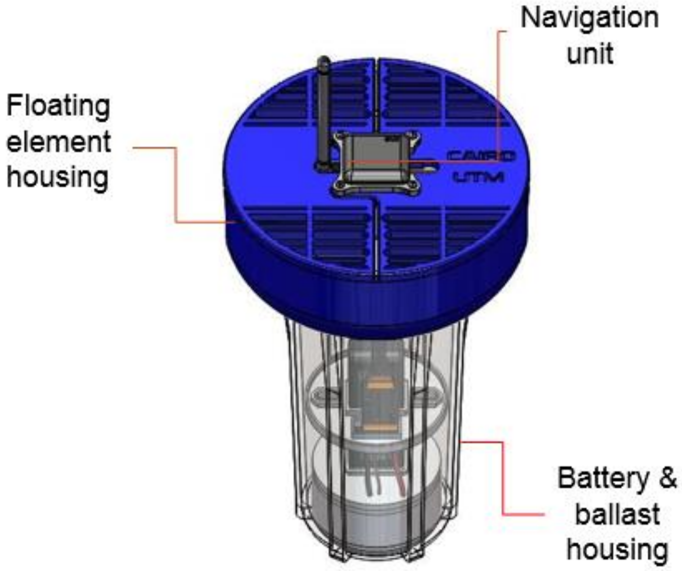


Figure 4. Passive floating sensor

Figure 5 depicts the position and mass of the major components of the assembly together with the center of gravity and the water level. From SolidWorks mass property evaluation, the center of gravity is 49.94 mm in the z direction from the principle axis (marked red cross in Figure 5). Water level is 122.10 mm in the z-direction from the principle axis (marked yellow dotted line in Figure 5).

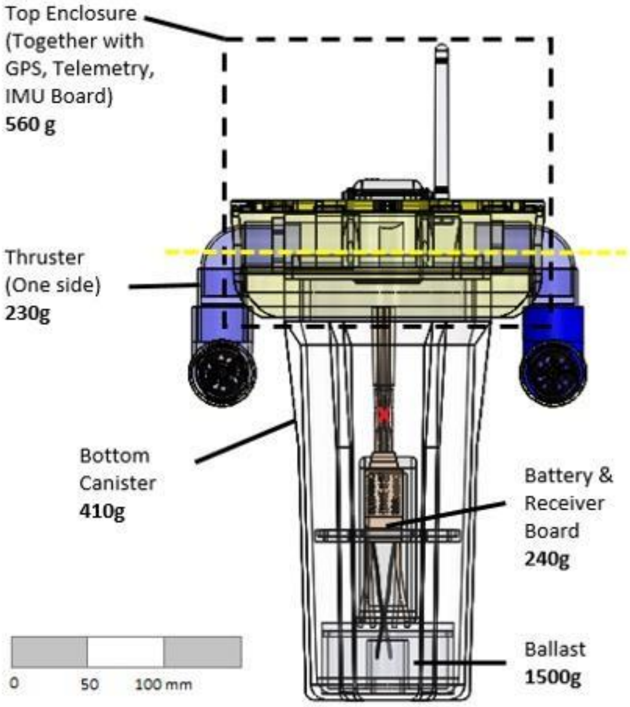


Figure 5. Mass of major components

Data from the sensors can be intercommunicated between a series of profilers to the ground station located in the working range of the radio transmission. Figure 6 shows a schematic of a series of 3 drifters sending and receiving GPS data while simultaneously providing the user at the ground station with each unit's unique individual data set and the actual position of the drifters in Google maps via Frequency Hopping Spread Spectrum.

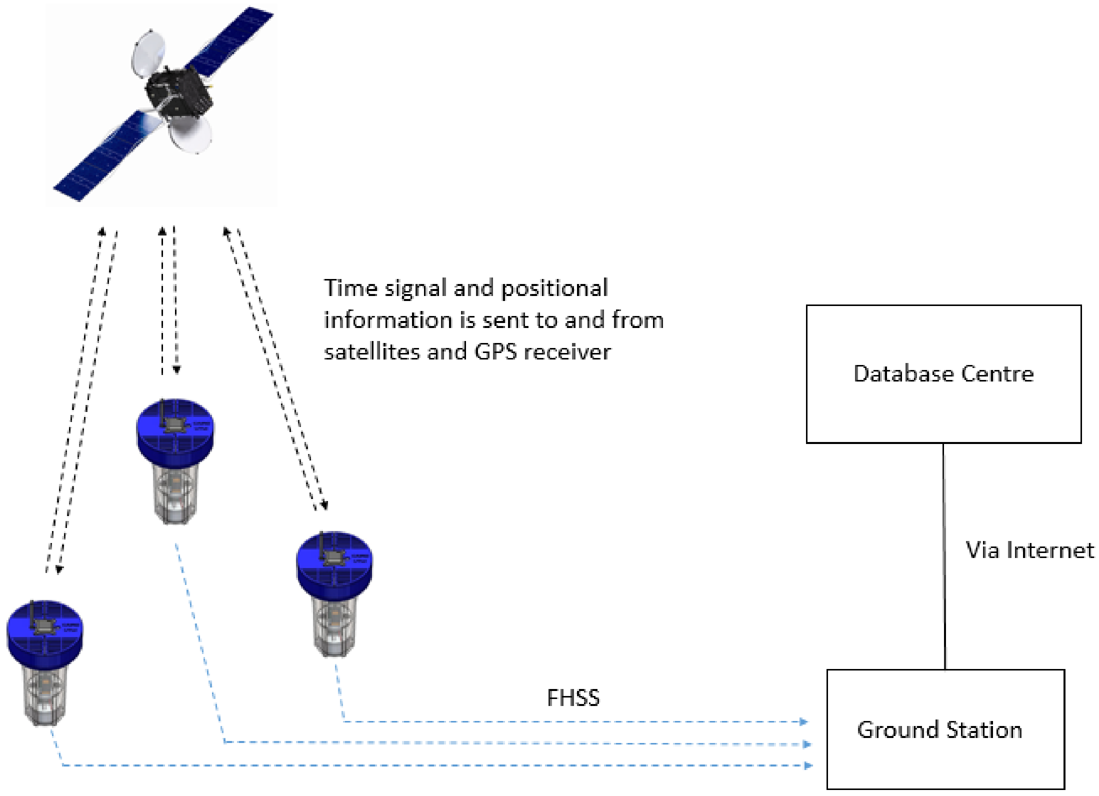


Figure 6. Diagram of multiple drifters

In Figure 7, the complete diagram inspired from Ishikawa 'cause and effect' framework [9, 12] shows the generic functional requirements of the drifters, while the Ishikawa diagram in Figure 8 depicts the same structure, but all the components replaced with in-depth design attributes.

System Specification

Figure 9 below shows the flow diagram of the AGV system where a seven channel radio system and telemetry is used to control and give live feed data to and from the floating sensor.

The communications between all components of the system use a protocol known as MAVLink. MAVLink is a lightweight, header-only message marshalling library for MAVs communicated in C/C++.

This data transfer encodes data structures into high efficiency data packets which use binary instead of ASCII encoding, yielding faster data transfer and higher data integrity [13]. Any device that can communicate in MAVLink can communicate to ArduPilot.

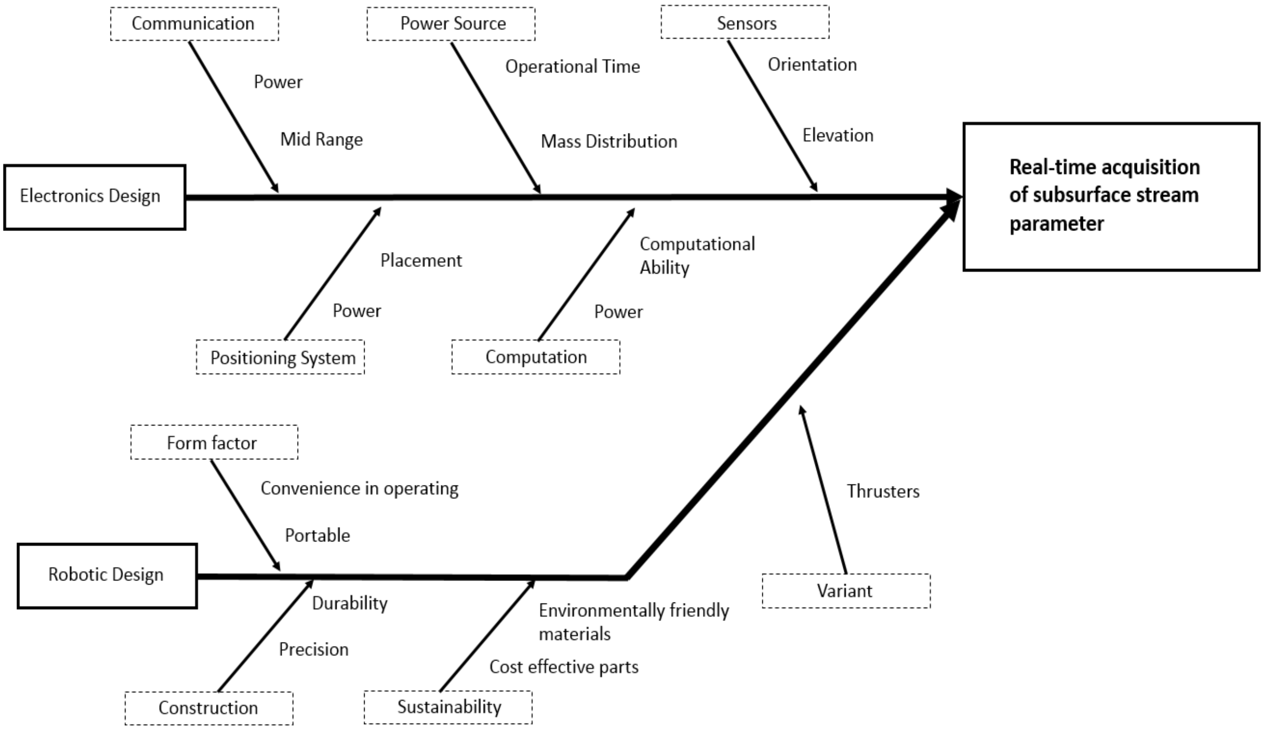


Figure 7. Complete Ishikawa diagram for design process with functional requirements

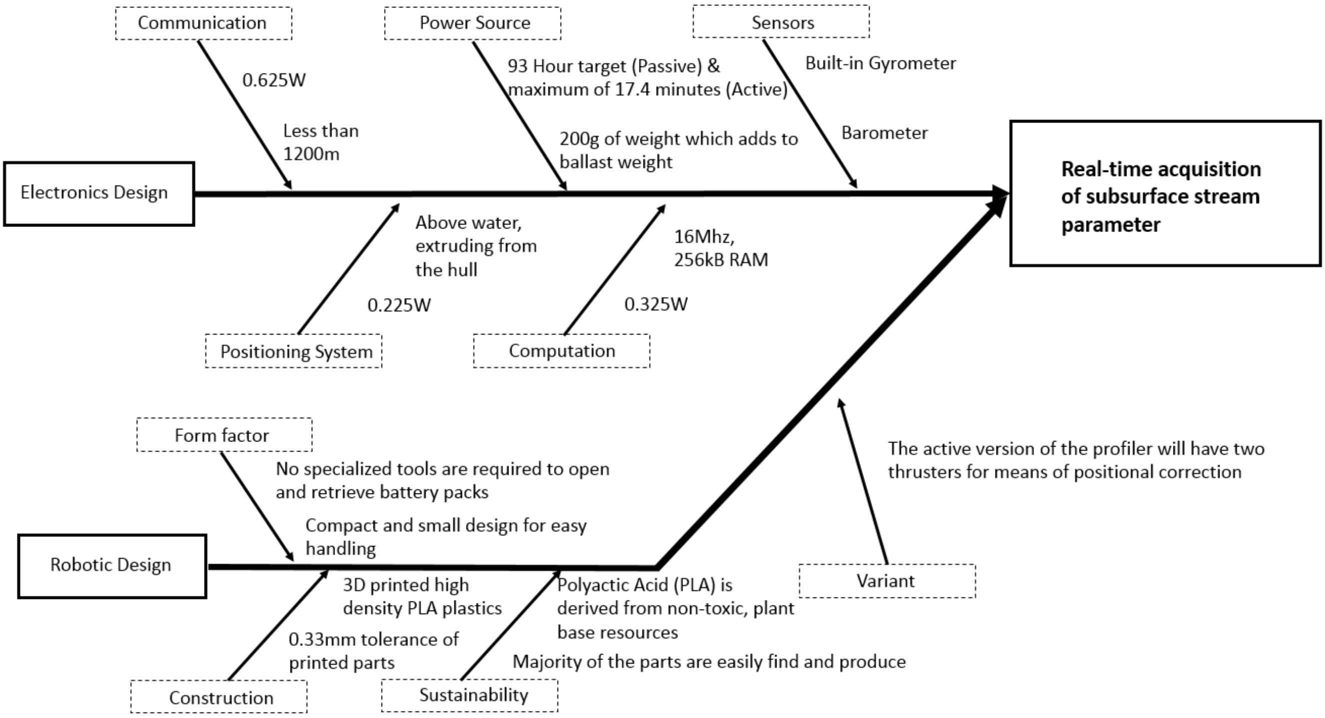


Figure 8. Complete Ishikawa diagram for design process with design attributes

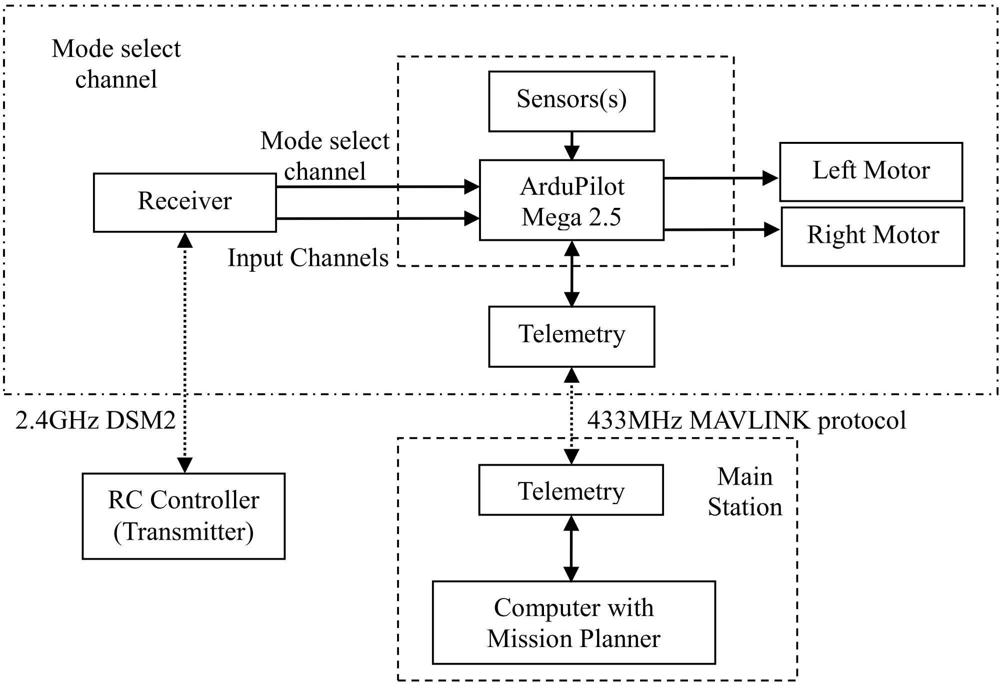


Figure 9. The overall system of the river floating sensor

A C++ wrapper has been developed that abstracts MAVLink so it can communicate over any physical transport layer, currently available is the communication over serial, TCP/IP, UDP, and write to file. This will facilitate the seamless transition in the testing phase in mission testing, by simply having each component change the physical means of sending MAVLink encoded data through USB cable.

The optional communication in this case the 3DR Radio for telemetry converts a serial stream to wireless using the same protocol which is MAVLink. A large outdoor 20 dBm (100mW) 433 MHz antenna is used on the ground station, and a 121 dBm receiver on the rover. This means that the small 100mW power of the telemetry can communicate with the rover almost 1.7 km away in any direction and orientation as well as features optional bi-directional amplifier for even more range. The 3DR telemetry uses Frequency Hopping Spread Spectrum (FHSS) that ensures the continuity of data transmission. Additionally, a 4mb data log is also available on the APM 2.5 board to collect various parameters such as velocity, heading, HDOP values, roll angle and power data. The 2.4 GHz Tx-Rx radio is used for mode switching and offers manual maneuverability for the user during initiation stage and collection.

Dynamics of Floating Sensor

As a freely moving body travels in a stream, it changes its state from distorted to steady in time. The larger the difference between both states, the more energy is transferred from the body of water to the body which implies the longer it would take before the body moves in similar velocity with the water.

The CFD tool used is the SolidWorks Flow Simulation, which is a software integrated in SolidWorks mainly for the purpose of computing fluid flow. The feature of Flow Simulation is its visually clear and clean interface which includes pre-processing data input (with Engineering Database for the material properties).

SolidWorks Flow Simulation works by obtaining solutions to the Navier-Stokes equations that govern the motion of fluids and it is able to compute the force, velocity, pressure and even the relative density of flow in a specified field [14].

The main goal of implementing the use if CFD analysis is to simulate the early stage effects of the external environment on the flow patterns of the passive drifter within a computational domain of 0.40 m by 0.35 m by 1.68m body of water with assumed constant flow of 0.87 m/s in z direction in the CFD.

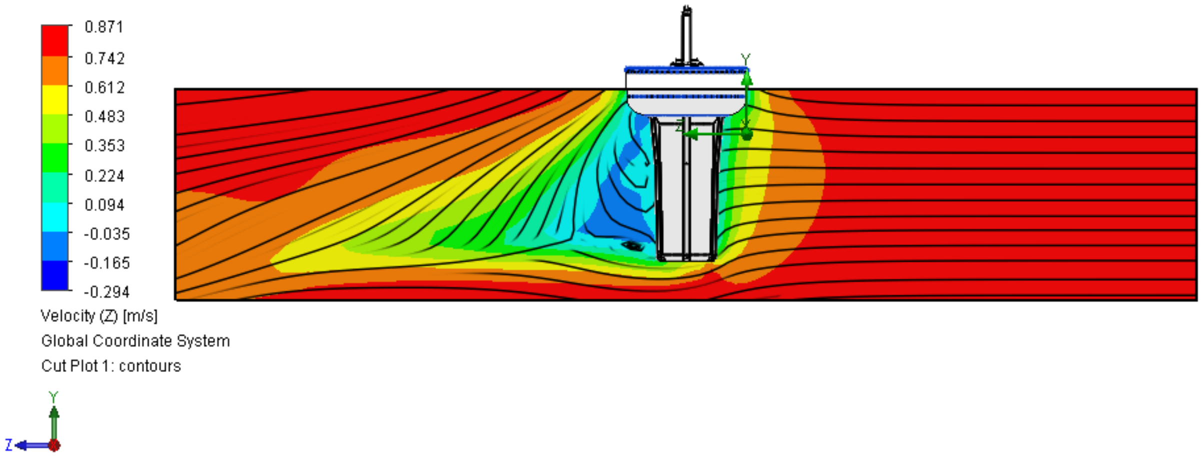


Figure 10. Passive drifter velocity contour and streamlines

Figure 10 shows the distribution of water at the cut plane at the center of the body viewed in parallel from the direction of flow at the moment when the drifter is placed in a moving body of water with 0.87 m/s of velocity. As the submersed section of the drifter is underwater, it will generate momentum to the whole body over time. From a close observation, it shows a considerable area of turbulence formed at the length of the hull which will assist the induction of drag [15]. Body drag is highly crucial in this project as more drag would yield shorter interval to a steady state, mimicking the subsurface stream velocity.

From the velocity (Y) data from Table 1, we know that the drifter design would yield a maximum of 0.75 m/s negative velocity of water which indicates the presence of high turbulence from the geometry of the drifter. The moving flow of fluid defined by dynamic pressure is at a maximum of 439.5 Pa from the simulation.

For the basis of dynamics model the drifters are deployed as passive Lagrangian tracers. In our framework, the drifters move along local flow streamlines [16], obeying the following equations:

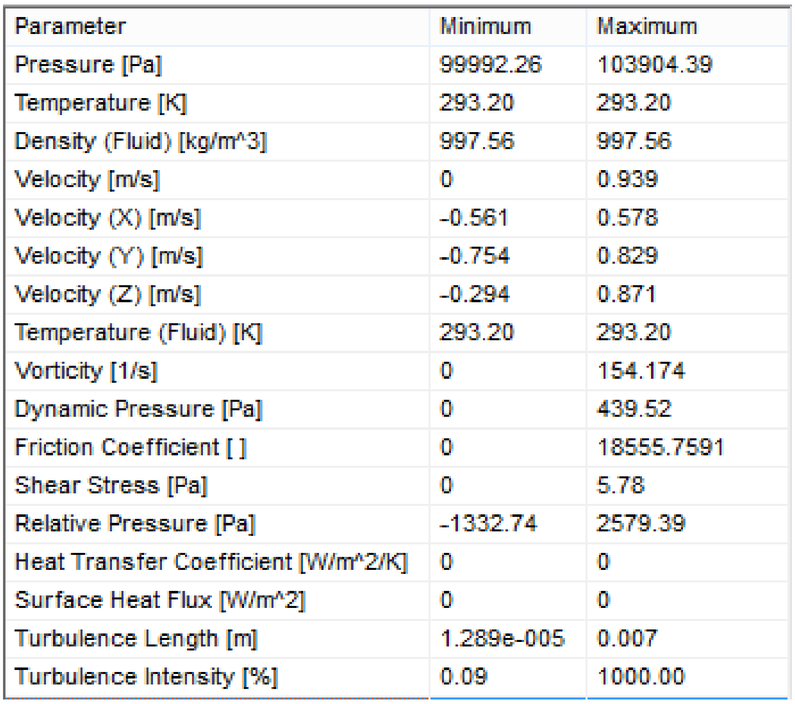
$$\frac{dx_D(t)}{dt} = u[x_D(t), y_D(t), t] \qquad (1)$$

$$\frac{dy_D(t)}{dt} = v[x_D(t), y_D(t), t] \qquad (2)$$

With initial conditions of drifter given as

$$x_D(t) = x_{D,o}, y_D(t) = y_{D,o} \qquad (3)$$

Table 1. Maximum and Minimum CFD Test Values



Parameter	Minimum	Maximum
Pressure [Pa]	99992.26	103904.39
Temperature [K]	293.20	293.20
Density (Fluid) [kg/m^3]	997.56	997.56
Velocity [m/s]	0	0.939
Velocity (X) [m/s]	-0.561	0.578
Velocity (Y) [m/s]	-0.754	0.829
Velocity (Z) [m/s]	-0.294	0.871
Temperature (Fluid) [K]	293.20	293.20
Vorticity [1/s]	0	154.174
Dynamic Pressure [Pa]	0	439.52
Friction Coefficient [ ]	0	18555.7591
Shear Stress [Pa]	0	5.78
Relative Pressure [Pa]	-1332.74	2579.39
Heat Transfer Coefficient [W/m^2/K]	0	0
Surface Heat Flux [W/m^2]	0	0
Turbulence Length [m]	1.289e-005	0.007
Turbulence Intensity [%]	0.09	1000.00

Data Sampling

After several test runs were commenced, various data were acquired in relation to time. From telemetry logs, there are a total number of 143 parameters that are automatically collected ranging from satellite numbers to remaining voltage of battery. The related parameters acquired from the data sent from the telemetry logs that are beneficial in the river study are as shown in Table 2.

Table 2. Main Parameters for River Monitoring

Parameter	Function
yaw (ATTITUDE)	Actual heading in centi degrees with 0 = north
lat (GPS_RAW_INT)	Lattitude according to the GPS
lng (GPS_RAW_INT)	Longitude according to the GPS
vel (VHR_HUD)	Horizontal ground speed in m/s
time_usec (GPS_RAW_INT)	GPS reported time since epoch in milliseconds

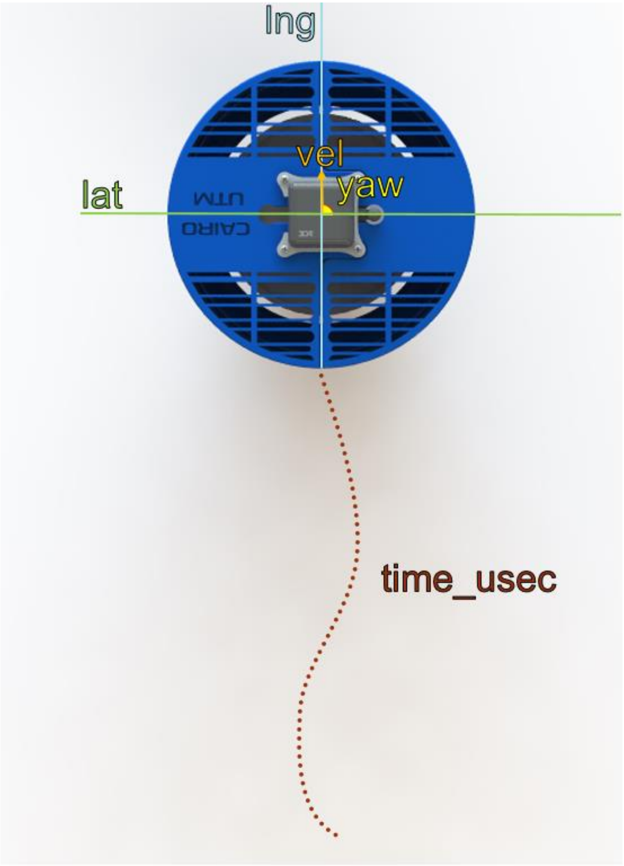
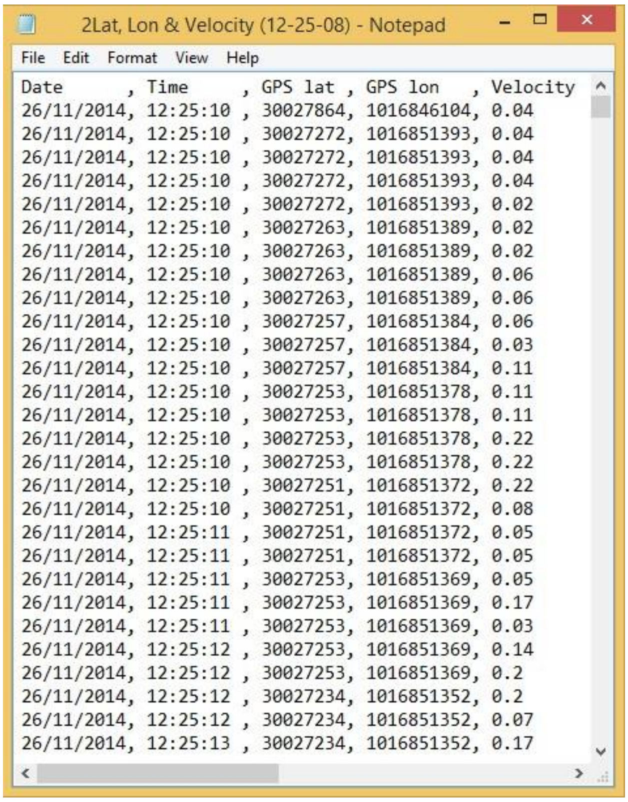


Figure 11. Description of adapted parameters from a plan view

From the data test run plotted on Google Maps as shown in Figure 12, the raw data that is acquired are as shown in Figure 13 taken from the actual raw data at the ground station. The data shows the date, time (from GPS), latitude, longitude, and velocity.

Figure 12. The path for the respective test



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Date       , Time      , GPS lat , GPS lon    , Velocity
26/11/2014, 12:25:10 , 30027864, 1016846104, 0.04
26/11/2014, 12:25:10 , 30027272, 1016851393, 0.04
26/11/2014, 12:25:10 , 30027272, 1016851393, 0.04
26/11/2014, 12:25:10 , 30027272, 1016851393, 0.04
26/11/2014, 12:25:10 , 30027272, 1016851393, 0.02
26/11/2014, 12:25:10 , 30027263, 1016851389, 0.02
26/11/2014, 12:25:10 , 30027263, 1016851389, 0.02
26/11/2014, 12:25:10 , 30027263, 1016851389, 0.06
26/11/2014, 12:25:10 , 30027263, 1016851389, 0.06
26/11/2014, 12:25:10 , 30027257, 1016851384, 0.06
26/11/2014, 12:25:10 , 30027257, 1016851384, 0.03
26/11/2014, 12:25:10 , 30027257, 1016851384, 0.11
26/11/2014, 12:25:10 , 30027253, 1016851378, 0.11
26/11/2014, 12:25:10 , 30027253, 1016851378, 0.11
26/11/2014, 12:25:10 , 30027253, 1016851378, 0.22
26/11/2014, 12:25:10 , 30027253, 1016851378, 0.22
26/11/2014, 12:25:10 , 30027251, 1016851372, 0.22
26/11/2014, 12:25:10 , 30027251, 1016851372, 0.08
26/11/2014, 12:25:11 , 30027251, 1016851372, 0.05
26/11/2014, 12:25:11 , 30027251, 1016851372, 0.05
26/11/2014, 12:25:11 , 30027253, 1016851369, 0.05
26/11/2014, 12:25:11 , 30027253, 1016851369, 0.17
26/11/2014, 12:25:11 , 30027253, 1016851369, 0.03
26/11/2014, 12:25:12 , 30027253, 1016851369, 0.14
26/11/2014, 12:25:12 , 30027253, 1016851369, 0.2
26/11/2014, 12:25:12 , 30027234, 1016851352, 0.2
26/11/2014, 12:25:12 , 30027234, 1016851352, 0.07
26/11/2014, 12:25:13 , 30027234, 1016851352, 0.17
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Figure 13. Raw data acquired

This shows that the floating sensors are able to record and transmit data in real-time in an extensive range from the ground station.

Conclusions

This paper describes an Ishikawa design methodology for river floating sensors. The data sampling from a case study performed in the actual controlled channel are presented to demonstrate the effectiveness of the design decisions as preliminary steps with limited accessible data collection. From the methods highlighted, continuous monitoring of specific and detailed hydrological situations cannot be satisfactorily performed using traditional means: direct measurements of the water properties based on Eulerian sensing. Following the experience in the field of geophysical monitoring through sensor network, the design approach described in this paper is an interesting alternative. In fact, it describes the concept of disposable sounding probes that are able to collect data directly from water even at relatively significant flow.

Acknowledgement

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