Establishing Autonomy on Chicago's Riverway Using Computational Approaches

Michael Valentino Ochoa (Updated: 2/13/20)

I. INTRODUCTION

In this paper we present the boat design, sensor kit and technology stack for an autonomous boat. The goal is for the boat to interpret data above and below the river in a way similar to how humans use their senses to relate to the world around them. (e.g. Where am I? Where is everyone else? How do I get from A to B?).

The two main contributions of this paper are designing suitable control laws for four predictive thrusters, on which collective algorithms for obstacle detection, lane keeping and active cruise control can be assessed. The second contribution is a customer facing business that blend old world traditions (Venetian water taxis) and the modern culture that characterizes Chicago (hospitality and autonomous technology).

II. MOTIVATION

Global sea level rise will be one of the greatest challenges facing our society this century, and understanding how this phenomenon will reverberate onto riverway communities will require a regular presence. We believe our autonomous boat can be that regular riverway presence.

This paper is laid out at follows:

Section III presents the boat design, sensor kit fabrication and bill of materials. Section IV draws out the technology stack for the Riverway Awareness and and Warning System (RAWS). Section V thru X describe (RAWS) in greater detail. Field testing setup and results are unpacked in Section XI, and Section XII gives way to the discussion. To conclude Section XIII presents the customer facing business.

III. BOAT HULL & SENSOR KIT

Our scale model prototype is rectangular shaped with the dimensions being approximately (0.9m x 0.45m x 0.1m). To ensure the weight is evenly distributed around its "center of buoyancy" (CoB) we laser cut marine grade plywood and 3D print various components to fabricate the hull. The components are married together by zip ties and epoxy thickened with wheat flour. Next, a mini computer, micro controller, wifi adapter, mobile beacon, four thrusters and solar panel are added to the boat.

Fig. 1. Boat Design & Sensor Kit

Next, the sensor kit is added to teach the boat to interpret the world around them in a way that is similar to the way human drivers use their senses to relate to the world around them. The sensor kit is made up of: (1) color camera, (2) 2D LiDAR sensors, (2) 24 GHz radar sensors, (1) sonar sensor and (1) Inertial Movement Unit (IMU) sensor which allow the boat to localize itself to sub-centimeter level precision.

Bill of Materials

Item	Price	Weight
Color Camera		
(2) LIDAR		
(2) Thermal		
Sonar		
IMU Sensor		
Mini Computer		
Micro Controller		
Wifi Adapter		
GPS Kit		
4 Thrusters	$500	
Solar Panel	$180	
Boat Hull, etc.		

IV. TECHNOLOGY STACK (RAWS)

// Sensors 1 //

Color Camera, Sonar
(2) 2D-Lidar & (2) Radar

// Sensors 2 //

GPS Position, GPS Compass, IMU

// Perception 1 //

River "Road" Finder, Vision Mapper, Laser Mapper, Radar Mapper

// Perception 2 //

Wave Ruggedness Index,
UKF Pose Estimation

// Planning & Control //

Wireless Emergency Stop, Path Planner, Thrusters Algorithm (Steering & Throttle/Brake)

// Boat and User Interface //

Touch Screen UI, Boat Interface,
Power Server Interface

// Global Services //

Linux Processes, "Heartbeats", Data Logger, Inter-Process Communication Server, File System

Fig. 2. Technology Stack (RAWS)

RAWS models the language of physics occurring on the water and decouples the optimization problem into approximately 20 modules across six interconnected layers detailed in sections V thru XI.

Generally speaking, the goal is to design suitable control laws for predictive four predictive thrusters, on which collective algorithms for obstacle detection, lane keeping and active cruise control can be assessed.

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V. BOAT STATE ESTIMATION

+ Where am I?

Inputs >>

Position & Compass (GPS)
Orientation (IMU)
Velocity

VI. RIVERWAY PERCEPTION

+ Where is everyone else?

For short and medium range obstacle avoidance up to 30m in front.

VII. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else (cont.) ?

VIII.WATER PROPERTY ESTIMATION

+ Where is everyone else (cont.) ?

Establishing wave ruggedness index.
UKF Pose Estimation

IX. PATH PLANNING

+ How do I get from A to B?

X. THRUSTERS ALGORITHM

+ How do I get from A to B?

Steering
Throttle/Brake
Emergency Stop

Once V thru IX has been established by RAWS, the most efficient steering, throttle/brake and steering commands are committed to safely guide the boat along its pre-planned open water route.

XI. FIELD TESTS & RESULTS

A. FIELD TESTING

+ WMS Boathouse to Riverwalk to Chinatown
+ River Use Characteristics
+ Perception of River
+ Local Demographics

B. BOAT STATE EST. DATA

C. RIVERWAY PERCEPT. DATA

D. DEEPER RIVERWAY PERCEPT. DATA

E. WATER PROPERTY EST. DATA

F. PATH PLANNING DATA

G. THRUSTERS ALGO. DATA

H. SAFETY TESTING DATA

XII. DISCUSSION & FUTURE WORK

In the paper we extend the capacity of an autonomous driving system to understand:

— Where am I?
— Where is everyone else?
— How do I get from A to B?

We run open water field tests in fog, smoke and rain to validate the efficiency and accuracy the our River Awareness Warning System and thruster algorithm. The field tests provide data that the boat uses to proactively improve its autonomous safety practices. The goal is to create an experience piloted by our autonomous boat that could impress both a safety and sustainability commissioner.

Future research will explore some of the most challenging problems in computer vision — segmenting overlapping data. Presenting a plausible model of computer vision across four different types of merged sensor data that sidesteps computational inefficiencies is difficult to do. Our research goes after the problem by adding small insights to Professor's Geoffrey Hinton's research and extend this technology to autonomous boats. Our work conceptualizes a prefrontal cortex, whose dopamine based architecture stamps in associations between pixel associations using "Dynamic Routing Between Capsules" Hinton et la. [2017]. This approach helps the autonomous boat establish its own mental rules and concepts to better distributes it payload around its "center of buoyancy" (CoB). The goal is to give boat an intrinsic motivation to play with it inputs and learn which data to hold onto, segment overlapping sensor data and explain its methods for computer vision with probabilities.

Second, our research will continue exploring how changing mass and drag effect the RAWS technology stack and thruster algorithm when transporting people and goods. And finally, better rationing materials, especially metal and delving into alternative durable materials drives our future work.

XIII. CUSTOMER FACING BUSINESS

We recognize there is an immense amount of noise in the autonomous transit industry. For years the challenge focused on engineering, but as autonomous technology becomes increasingly commodified, trying to build services in a new regulatory environment will be the next challenge.

By targeting riverway transit's weaknesses — an uncomfortable and sometimes inhospitable image — a clever startup with the right strategy, the right message and the right product could create a new riverway transit brand for the new decade.

Our business is focused on being public transit that prepares people to take on the city, a kind home-away-from-home on the river. We believe in letting our autonomous system do what it does best (e.g. obstacle detection, lane keeping and active cruise control) and letting our captains aboard the boats do what we do best (e.g. be the social and hospitable animals we are).

Our transit will be available from 4-7p nightly Monday thru Saturday. Pickup points will be between the WMS Boathouse (3400N), the Riverwalk (200N) and Ping Tom Memorial Park (1800S) with boats making pickups at from these points on the hour. Each boat seats up to 16 riders. The service seeks to help non-locals see the city and locals move about the city.

At a time when our generation faces ecological, economic and values crises, some of the most essential technology in navigating the path ahead is not the autonomous boat we outlined above. A future governed by rationality and data offers no space in these times, there's just too many ecological, economic and values tradeoffs needed to meet the aspirations of our wonderfully diverse humanity. Our vision of autonomous boat is not necessarily the answer, but rather a step in a creative learning process towards healthier cities.

XIV. REFERENCES

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