Establishing Autonomy on Chicago's Riverway Using Computational Approaches

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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). 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, our 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 in Chicago's rivers to sub-centimeter level precision.

Bill of Materials

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

IV. TECHNOLOGY STACK (RAWS)

// Sensors 1 //

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

// 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 Control & 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

RAWS absorbs and 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 drive the error of selected variables to zero to safely guide the boat along a preplanned open water route.

V. BOAT STATE ESTIMATION

+ Where am I?

Inputs >>

Position (GPS)
Velocity
Orientation (IMU)

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

+ How do I get from A to B?

Establishing wave ruggedness index.

IX. PATH PLANNING

+ How do I get from A to B?

X. THRUSTERS ALGORITHM

+ How do I get from A to B?

+ Steering Control
+ Throttle/Brake

Once the intended path of the boat has been established by the path planner, the most efficient throttle, brake and steering commands are committed with respect to driving the error of selected variables to zero to guide the boat along a pre-planned open water route.

XI. FIELD TESTS & RESULTS

A. FIELD TEST SETUP

+ East Bank Club > Weed St Boathouse
+ 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 of (RAWS) and our thrusters 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 a safety and sustainability commissioner.

One of the most challenging problems in computer vision is dealing with segmentation in overlapping data. Presenting a plausible model of object recognition that avoids exponential inefficiencies is difficult to do. Our research builds upon the fundamental research of Professor Geoffrey Hinton, and adds small insights to extend this technology to autonomous riverway transit. Future work conceptualizes a prefrontal cortex, whose dopamine based architecture stamps in association between pixel associations using "Dynamic Routing Between Capsules" Hinton et la. [2017]. This approach helps the boat establish its own mental rules, concept and analogies for the riverway. The goal is to give boat an intrinsic motivation to play with it inputs and learn which data to hold onto, segment overlapping data and explains it methods for object recognition with probabilities.

Second, our research will continue exploring how changing mass and drag effect the 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 humans safety drivers aboard the boats do what we do best (e.g. be the social and hospitable animals we are).

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 system we outlined above. A future governed by rationality and science offers no space in these times, there's just too many social and environmental tradeoffs needed to meet the aspirations of our wonderfully diverse humanity. Our vision of autonomous transit on the river may not be the answer, but rather a step in a creative learning process towards healthier cities.

XIV. REFERENCES

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