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 the fun part - a shared 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 the boat's four predictive thrusters, on which *collective algorithms for obstacle detection, lane keeping, active cruise control, buoyancy, drag and center of buoyancy* can be assessed. The second addition is a plan for a customer facing business that blend old world traditions (Venetian water taxis) and the modern culture that characterizes Chicago (hospitality and shared autonomous transportation services).

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 transportation service 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 dimensions (0.9m x 0.45m x 0.1m). To fabricate the hull we laser cut marine grade plywood and couple it with some 3D printed components. Next, within a leak proof housing we add a mini computer, micro controller, wifi adapter, mobile beacon. Finally our four thrusters and solar panel are folded into the design. The components are married together with zip ties and epoxy thickened with wheat flour.

Fig. 1. Boat Design & Sensor Kit

With the hull now designed we added our sensor kit to begin teaching the boat to interpret the world in a way that is similar to the way human drivers use their senses to relate to the world around them. The boat's sensor kit consists of: (1) color camera, (2) 2D LiDAR sensors, (2) thermal radars, (1) sonar sensor and (1) Inertial Movement Unit sensor (IMU) which help the boat to localize its buoyancy, drag and center of buoyancy (CoB) 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 (Riverway Awareness Warning System — RAWS)

// Sensors A //

RGB-Camera, Thermal Radar (2)
2D-Lidar (2), Sonar

// Sensors B //

GPS Position, GPS Compass, IMU

// Perception A //

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

// Perception B //

Wave Ruggedness Index
Pose Estimation

// Planning & Control //

Path Planner, Thrusters Algorithm (Steering Angle, Throttle/Brake, Emergency 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)

Our technology stack (RAWS) models the language of physics happening 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 of RAWS is to design suitable control laws for predictive four predictive thrusters, on which collective algorithms for *obstacle detection, lane keeping, active cruise control, buoyancy, drag and center of buoyancy* can be assessed.

V. BOAT STATE ESTIMATION

+ Where am I?

Inputs >>

Position & Compass (GPS)
Orientation (IMU)
Velocity

VI. RIVERWAY PERCEPTION

+ Where is everyone else?

River "Road" Finder

VII. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else (cont.) ?

Vision / Laser / Radar Mapping

VIII.WATER PROPERTY ESTIMATION

+ Where is everyone else (cont.) ?

Wave Ruggedness Index
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 Angle
Throttle/Brake
Emergency Stop

XI. FIELD TESTS & RESULTS

A. FIELD TESTING

+ Julia C. Lathrop Homes (2800N) thru Park No. 571 (2800S)
+ River Use Characteristics
+ Perception of River
+ Local Demographics

B. SIMULATION DATA

C. FIELD 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 the *collective algorithms for obstacle detection, lane keeping, active cruise control, buoyancy, drag and center of buoyancy.*

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 more challenging problems in computer vision — mapping the real physical river. It changes fast, and it's very big. Presenting a model of computer vision stretching across four types of sensor data while sidestepping computational inefficiencies will be a challenge. Our research goes after the problem by adding small insights to Professor's Geoffrey Hinton et la.'s research and extending their research to shared 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]. We believe this approach helps the autonomous boat establish its own mental rules about planning, execution, and learning how to safely and efficiently safely navigate Chicago's riverways along preplanned open water routes. The goal is to give boat an intrinsic motivation to learn the "corner cases" that will exist on Chicago's riverways.

Additional research includes: exploring how changing mass and drag effect the thrusters algorithm when transporting people and goods; learning to better rationing boat materials and delving into alternative durables.

XIII. CUSTOMER FACING BUSINESS

A. WHAT IS THE PROBLEM?

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

B. VALIDATING PROBLEM

Targeting public transit's weaknesses — it's crowded and uncomfortable during rush hour — a clever transit startup with right strategy (shared autonomous boat), right message (catchy and light-hearted inclusivity) and shockingly superior product (a better ride all around) could be the new transit brand for the emerging riverway experience.

C. SOLUTION

Our 16 seat autonomous boat (w/ human aboard) is available 4-7p Monday thru Saturday. Pickup points are between Julia C. Lathrop Homes (2800N), Lincoln Yards (1900N) the Riverwalk (200N), The 78 (600S), Ping Tom Memorial Park (1800S) and Park No. 571 (2800S). The boat moves from start to finish almost like a cable car on the water.

D. MAKING MONEY

~~For a flat rate our service comfortably moves locals about the city and helps non-locals see the city. Aboard the boat we sell "Poretta Boxes" (a prosciutto panino, a piece of fruit, a chunk of parmigiana and a half bottle of wine) as well as "curated experiences" for guests after hours.~~

E. WHAT WE DIFFERENT?

Our business is focused on being an experience 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 humans 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 best solutions in navigating the path ahead may not be our autonomous boat. A future governed by data and rationality may be too much in these times, there's just too many ecological, economic and values tradeoffs needed to meet the aspirations of our wonderfully diverse city. Our vision of an 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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