Establishing Autonomy on Chicago's Riverway Using Computational Approaches

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I. INTRODUCTION

In this paper we present the hull design, sensor kit and technology stack fort an autonomous boat. The boat's goal is 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 thrusters, on which *collective algorithms for obstacle detection, lane keeping, active cruise control, center of buoyancy and minimizing drag* can be assessed. The second contribution is customer facing business plan that blends old world traditions (Venetian water taxis) and the modern culture that characterizes Chicago (hospitality and 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 hull design and sensor kit. 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 and results are unpacked in Section XI and Section XII gives way to the discussion. To conclude Section XIII presents the plan for a customer facing business using this technology.

III. HULL DESIGN & SENSOR KIT

It's an age old question, should you transport more people/cargo on a slow boat, or less people/cargo on a faster low wake boat. We believe in the latter and designed a low wake hull with a hydrofoil to navigate Chicago's riverway.

At low speeds our boat's scale model hull (approximately 1:8) sits in the water while hydrofoils (a wing/foil under boat's hull used to lift the boat outside the water) remains submerged. Tho as speed increases the hydrofoils create lift and at a certain speed the hydrofoil equals the sum of the boat's people/cargo so the boat comes out the water. We believe our hydrofoil design is an efficient way of cruising Chicago's no wake riverways.

To fabricate the catamaran-inspired 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 thrusters and solar panel are folded into the design. The components are married together with zip ties and epoxy thickened with wheat flour to establish our proof of concept.

Fig. 1. Boat Design

With the hull designed we then add our sensor kit consisting of: (1) color camera, (2) 2D LiDAR sensors, (2) thermal radars, (1) sonar sensor, GPS kit and (1) Inertial Movement Unit sensor (IMU) which help the boat to localize its drag, center of buoyancy and location to sub-centimeter level precision.

Fig. 2. Sensor Kit

IV. TECHNOLOGY STACK (Riverway Awareness Warning System a.k.a. 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. 3. 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 the boat's thrusters, on which *collective algorithms for obstacle detection, lane keeping, active cruise control, center of buoyancy and minimizing drag* can be assessed.

V. BOAT STATE ESTIMATION

+ Where am I?

Inputs >>

Position & Compass (GPS)
Orientation (IMU)
Velocity

VI. RIVERWAY PERCEPTION

+ Where is everyone else?

VII. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else (cont.) ?

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

Establishing repeatable environments for testing our approaches for exploration, learning and navigation is essential. That in mind our first testing ground moves between the Julia C. Lathrop Homes (2800N) and Park No. 571 (2800S) on Chicago's riverways.

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?
— How can higher level concepts be learned from intermediate level sensor data?

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, center of buoyancy and minimizing drag.*

Our field tests provide data that the boat uses to proactively improve its autonomous safety practices. The goal is to create an experience piloted 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's something that changes fast and is very big. Presenting a model stretching across multiple types of pixel-level sensor data while sidestepping computational bottlenecks will be a challenge. Our research approaches the problem by adding small insights to Professor's

Geoffrey Hinton et la.'s research and extending their research to our autonomous boat. We conceptualize a prefrontal cortex, whose dopamine based architecture stamps in associations between pixel associations using "Dynamic Routing Between Capsules" Hinton et la. [2017] and "Learning to Explore Using Active Neural Slam" Devendra Singh Chaplot et la. [2019]. We believe our approach helps the boat establish its own mental rules about safely and efficiently navigating preplanned routes on Chicago's riverways. The goal is to give boat an intrinsic motivation to learn the "corner cases" that inevitably exist on Chicago's riverways.

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 the tech becomes increasingly commodified, trying to build indispensable services in a new regulatory environment will be the next challenge.

B. VALIDATING PROBLEM

By targeting public transit's weakness — it's crowded and uncomfortable during rush hour — a clever transit startup with the right strategy, the right message and superior product could emerge as a front runner in the emerging urban transit experience.

C. SOLUTION

Our 16 seat autonomous boat (w/ human aboard) will be 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 roving cable car on the water.

D. MAKING MONEY

To get the register ringing we charge a flat rate to move locals/tourists about the city. Aboard the boat we also sell "Poretta Boxes" (a prosciutto panino, a piece of fruit, a chunk of parmigiana and a beverage). Finally we'll offer "curated experiences" for guests seeking a cannabis driven tour of Chicago's rivers.

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. Our hope it to incite some newfound sociability around riverway transit. We believe in letting our autonomous system do what it does best (e.g. obstacle detection, lane keeping, active cruise control, etc.) and letting our humans aboard the boats do what we do best (e.g. be the social and hospitable animals we are).

Though to be honest, 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 autonomous boats. A future governed by tech 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 a solution answer, but rather a step in a creative learning process towards healthier cities.

XIV. REFERENCES

Geoffrey E. Hinton et la., "Dynamic Routing Between Capsules," arVix:1710.09829, November 2017

O.B. Yaakob et la., "Parametric Study of a Low Wake-Wash Inland Waterway Catamaran, " in Scientia Iranica 19(3):463—471, June 2012

Sebastian Thurn et la., "Stanley: The Robot that won the DARPA Grand Challenge," in Journal of Robotic Systems, September 2006

W. Wang, L. A. Mateos, S. Park, P. Leoni, B. Gheneti, F. Durate, C. Ratti and D. Rus, "Design, modeling and nonlinear model predictive tracking control of a novel autonomous surface vehicle," in 2018 IEEE International Conference on Robotics and Automation (ICRA), May 2018, pp. 1-5.

APPENDIX A

Sensor Kit Beta_v0 Detailed

CAMERA	**#**
Capture Frequency	
Resolution	
Encoding	
Bandwidth	
LIDAR	
Capture Frequency	
# of Beams	
Certical FOV	
Range	
Accuracy	
Points Per Second	
Bandwidth	
RADAR	
Capture Frequency	
Operating Frequency	
Range	
Bandwidth	

APPENDIX A (CONTINUED)

Bill of Materials

ITEM	PRICE ($)	WEIGHT (Grams)
RGB-Camera		
Lidar		
Thermal Radar		
Sonar		
IMU Sensor		
GPS Kit		
Mini Computer		
Micro Controller		
Wifi Adapter		
Thrusters		
Solar Panel		
Boat Hull Design, etc.		