Establishing Autonomy on Chicago's Riverway Using Computational Approaches

Michael Valentino Ochoa (UPDATED: 2/23/20)

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 water 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 steering dynamics, on which collective algorithms for steering angle, throttle and brake on which *collective algorithms for obstacle detection, lane keeping, active cruise control and localizing the boat's center of buoyancy* can be assessed. The second contribution is a 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 boat 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 boat. We believe less is best designed an ultra low wake hull to move people/ cargo along Chicago's riverways.

To establish the hull (approximately 1:8) we use simulation software to flush out the design of an ultra low wake catamaran inspired hull. To fabricate the low wake hull we laser cut marine grade plywood from blueprints provided by the simulation software and couple it with 3D printed components. Next, within a leak proof housing we added a mini computer, micro controller, wifi adapter, mobile beacon. Finally thrusters and solar panels were folded into the hull's body. The boat's components were then 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 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 center of buoyancy and GPS location to centimeter level precision.

Fig. 2. Sensor Kit

IV. RIVERWAY AWARENESS AND WARNING SYSTEM (RAWS)

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

Software Packages

Ada_Localization

Localizes the boat's center of buoyancy and GPS location to centimeter level precision.

Ada_WaterProperties

Isolates the movement caused by choppy open waters with some sophisticated math to establish a wave ruggedness index.

Ada_PathPlanning

Ada_Autonomy

Establishes suitable control laws for the boat's thrusters using a dopamine based architecture on which collective algorithms for steering angle, throttling and braking can be assessed.

Ada_HullDesign

Leverages existing software to flush out the design of a low wake catamaran inspired hull (with hydrofoil).

Ada_Core

Ada_Utils

Ada_Launch

PointCloudLib1

Segments overlapping point cloud data across 2D-Lidar, thermal, sonar and RGB camera data

Drivers for Sensors, etc.

Technology Stack

Sensors A

Camera, Thermal Radar
2D-Lidar, Sonar

Sensors B

GPS Position, GPS Compass, IMU Sensor

Perception A

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

Perception B

Wave Ruggedness Index
Pose Estimation

Planning & Control

Path Planner, Steering Dynamics (Steering Angle, Throttle/Brake)

Boat and User Interface

Touch Screen UI, Boat Interface
Power Server Interface,
Emergency Brake

Global Services

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

V. BOAT STATE ESTIMATION

+ Where am I?

Gathering GPS position and IMU data to help the boat better define the applied force and moment vector for subsequent modules.

VI. RIVERWAY PERCEPTION

+ <u>Where is everyone else?</u>

The camera pixels inside of a quadrilateral approximately 30 meters ahead of the boat are used as training examples to establish a deeper understanding of drivable waters.

VII. DEEPER RIVERWAY PERCEPTION

+ <u>Where is everyone else?</u>

VIII.WATER PROPERTY ESTIMATION

+ <u>Where is everyone else?</u>

IX. PATH PLANNING

+ <u>How do I get from A to B?</u>

A search algorithm minimizes the continuous kinematic and dynamic cost functions.

X. STEERING DYNAMICS

+ <u>How do I get from A to B?</u>

Once the intended path has been established by the path planner, the most efficient steering angle and throttle/brake commands are chosen to safely guide the autonomous boat along its preplanned route.

XI. FIELD TESTS & RESULTS

A. FIELD TESTING SETUP

Establishing repeatable environments for testing the boat's methods for navigation and learning is essential. Our testing ground stretches along the North and South Branches of the Chicago River between the Julia C. Lathrop Homes (2800N) and Park No. 571 (2800S).

B. RESULTS

The simulation software used in this study models the boat's computational fluid dynamics to investigate how to streamline services, etc.

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, rain and dynamic lighting to validate the efficiency and accuracy of our boat's collective algorithms for obstacle detection, lane keeping, active cruise control and localizing the boat's center of buoyancy. The field tests data helps the boat proactively improve its autonomous practices. The goal is to create an experience 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, as it's something that changes fast and is very big. Our research approaches the problem by adding small insights to Professor's Geoffrey Hinton et la.'s research. We extend their research to conceptualize a prefrontal cortex, whose dopamine based architecture stamps in associations between sensor kit data using "Dynamic Routing Between Capsules" Hinton et la. [2017]. We believe our approach helps the boat establish its own mental rules about how to safely and efficiently navigate preplanned routes on Chicago's riverways. The goal is to give the boat an intrinsic motivation to learn the "corner cases" that exist on Chicago's riverways.

XIII. CUSTOMER FACING BUSINESS

A. WHAT IS THE CUSTOMER? WHAT PROBLEM DO WE SOLVE FOR THEM?

Through the eyes of our customers our business is just another way to commute along Chicago’s riverways. What we do different is target public transit’s weaknesses — it’s crowded, slow and uncomfortable during rush hour. We remedy the experience with a light heartened inclusivity, comfortable seating and shockingly smooth experience during rush hour. The goal is to be a front runner in the emerging Chicago River experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

To validate the problem we developed a 16 item questionnaire to better understand people’s perceptions, preferences and attitudes about riverway transit. Our survey was tested on 32 respondents across different ages, neighborhoods, races, gender and family income level.

C. OUR SOLUTION

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

Our solution is a 16 seat low wake autonomous boat with human safety driver aboard. The boat will be available for 3 roundtrips in the AM and 3 roundtrips in the PM Monday thru Friday between the Julia C Lathrop Homes (2800N) and Park No, 571 (2800S) on the Chicago Rivers.

D. MAKING THE REGISTER RING

We plan to make money by transporting people/cargo, almost like a roving cable car on the river. We charge a flat rate to transport local/ tourists along the river / we offer “buyouts” for groups seeking a cannabis inspired tour of the rivers / and we sell “Poretta boxes” (bread, slices of prosciutto, a piece of fruit, a chunk of parmigiana and beverage) during the lunch rush along highly foot trafficked areas of the river.

E. WHAT MAKES US UNIQUE?

Our unique approach blends hospitality and autonomy to help people take on their commute — almost like a kind of home-away-from-home on the river. We hope to incite some newfound sociability around riverway transit.

Generally speaking, our business believes in letting our autonomous boat do what it does best (e.g. obstacle detection, lane keeping, 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).

F. WHAT KEEP US UP AT NIGHT?

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 this tech-centric thinking may be too much in these times, as 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

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.

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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 B

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.		