A Growing Presence on the River: Autonomous Boats

Michael Valentino Ochoa (LAST REVISION: 2/28/20)

I. INTRODUCTION

In this paper we present the hull design, sensor kit and technology stack for an autonomous boat. The boat's goal is to generate a detailed portrait of the river and navigate the world around them, similar to how humans drivers use their own senses and intuition (i.e. Where am I? Where is everyone else? How do I get from A to B?).

The two major contributions of this paper are designing suitable control laws for the boat's steering dynamics (steering angle, throttle/brake), on which collective algorithms for lane keeping, obstacle detection, active cruise control and localizing its 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, delivery systems 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 structured as 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 XI describe RAWS in greater detail. Field testing and results are unpacked in Section XII and Section XIII gives way to the discussion. To conclude Section XIV presents the customer facing business plan.

III. HULL DESIGN & SENSOR KIT

It's an age old question, should you transport more cargo/people on a slow boat, or less cargo/people on a faster boat. We believe is less best.

To establish the hull's design we use simulation software to fabricate a catamaran inspired hull. To construct the hull (approximately 1:8) we laser cut marine grade plywood and couple it with 3D printed components. Next, within a leak proof housing we add a mini computer, micro controller, wifi adapter and GPS beacon. The boat's components are then married together with zip ties and epoxy thickened with wheat flour. Finally solar panels, energy storage and thrusters are added to establish our proof of concept.

With the hull and body established we add our sensor kit consisting of: (1) high definition color camera, (2) 2D LiDAR sensors, (2) thermal radars, (1) sonar sensor and (1) Inertial Movement Unit sensor (IMU) which help the boat localize itself to centimeter level precision.

Fig. 1. Boat Design & Sensor Kit

IV. RIVERWAY AWARENESS AND WARNING SYSTEM (RAWS)

Our technology stack, which goes by the name of RAWS models the language of physics/computer vision happening on the water and decouples the optimization problem into approximately six interconnected layers detailed in sections V thru XI.

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Technology Stack

Sensors A

High Definition Color Camera,
Thermal Radar, 2D-LIDAR, Sonar

Sensors B

GPS Beacon, IMU Sensor

Perception A

River "Lane" 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?

Construct a particle filter and blend it with a real map to localize the boat using GPS Beacon and IMU sensors

— Markov Localization
— Motion Models

VI. RIVERWAY PERCEPTION

+ Where is everyone else?

Identify "lanes" and classify obstacles using the boat's front facing camera

— Tensorflow + CNN

VII. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else?

Determine with certainty the location of others, especially moving obstacles using thermal radar, 2-D LIDAR, sonar

— Kalman Filters

VIII. WATER PROPERTY ESTIMATION

+ Where is everyone else?

Set maximum speed based on the shock imparted using IMU sensor

— Wave Ruggedness Index

IX. BEHAVIORAL CLONING

Train a neural net to drive autonomous boat like human safety driver

— Keras + Transfer Learning

X. PATH PLANNER

Guide the boat along a pre-planned open water route by minimizing cost functions

XI. STEERING DYNAMICS

+ How do I get from A to B?

Send steering, throttle and brake commands to thrusters

— Proportional-Integral-Derivative (PID)
— Model Predictive Controller

Fig. 2. Force Vectors on Boat

XII. FIELD TESTS & RESULTS

A. FIELD TESTING SETUP

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

B. RESULTS

XIII. DISCUSSION & FUTURE WORK

In the paper we extend the capacity of an autonomous robotic boat 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, rain, smoke and dynamic lighting to validate the efficiency and accuracy of the boat's algorithms. Field testing data helps the boat proactively improve its autonomous practices for lane keeping, obstacle avoidance, active cruise control and localizing its center of buoyancy. 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 autonomous transportation — mapping real physical rivers, as they're something that change fast and are very big. Our research extend's Professor Geoffrey Hinton et la.'s research to conceptualize a dopamine based architecture that stamps in associations between pixel-level sensor data flows. We believe this approach help the boat establish its own "rules of thumb" about how to safely navigate its preplanned open water routes. The goal is to give the boat an intrinsic motivation to store its own cognitive maps as probability models, and better learn the "corner cases" that exist on Chicago's Rivers.

XIV. CUSTOMER FACING BUSINESS

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

Through the eyes of customers we're just another way of moving cargo/ people. Tho what we do different is target transportation's weaknesses — it's crowded, slow and uncomfortable during rush hour. We remedy the experience with a light heartened inclusivity, comfortable experience and shockingly smooth experience on the river. The goal is to be a front runner in the emerging Chicago Riverway transportation and delivery experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

Our business was envisioned to reduce traffic congestion and help communities move cargo/people. We see Chicago's Riverways almost like a giant express lane slicing thru the city.

To validate the congestion problem we developed a 16 item questionnaire to better understand people's perceptions, preferences and attitudes about riverway transportation services. 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 transportation industry. For years the challenge focused on engineering, but as the technology gets increasingly commodified, trying to build services in a new regulatory environment has become the new challenge.

Our solution is a low wake autonomous boat with human safety driver aboard. The boat uses a high definition camera and sensors to generate a detailed portrait of the river to intelligently control its steering dynamics. The boat will be available for 3 roundtrips in the AM, 3 roundtrips in the PM and riverside deliveries throughout the day between the Julia C. Lathrop Homes (2800N) and Park No. 571 (2800S) along the North and South Branches of the Chicago River.

Fig. 3. Conceptual Rendering

D. MAKING THE REGISTER RING

We plan to make money by: (1) delivering cargo/people almost like a riverway cable car (2) charging a flat rate to transport people along the river (3) offering "buyouts" for groups seeking a cannabis/BYOB inspired tour of the river (4) moving cargo for a flat rate (5) selling "Poretta boxes" (bread, slices of prosciutto, a piece of fruit, a chunk of parmigiana and beverage) during the lunch rush along highly trafficked areas of the river.

E. WHAT MAKES US UNIQUE?

Our unique approach blends hospitality and autonomy to help riverway communities with their deliveries/commute. We hope to incite some newfound sociability around riverway transportation, almost like home-away-from-home/roving corner store on the river.

Generally speaking, our business believes in letting autonomous boats do what they do best (e.g. lane keeping, obstacle detection, active cruise control) and letting humans aboard the boats do what we do best (e.g. be the clever 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. Technology is not a cure-all solution, but it offers an opportunity to fundamentally redesign systems that help cargo/people get where they need to go with less inputs. Our vision of an autonomous boat is not necessarily the answer, but rather a step in a creative learning process towards healthier cities :)

XV. REFERENCES

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Jessie Levinson and Sebastian Thrun, ”Robust Vehicle Localization in Urban Environments Using Probabilistic Maps”, *International Conference on Robotics and Automation (ICRA)*, 2010

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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.		

APPENDIX B

Software Packages

Tripp_Localization

Localizes the boat's center of buoyancy and GPS location

Tripp_WaterProperties

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

Tripp_PathPlanning

Tripp_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.

Tripp_HullDesign

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

Tripp_Core

Tripp_Utils

Tripp_Launch

Drivers for Sensors

Robot Operating System, etc.