What Makes Chicago's Rivers Look Like Chicago? A Ethnographic Study Using Autonomous Boats

Michael Valentino Ochoa (LAST REVISION: 3/5/20)

I. 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 and human safety driver can be that regular riverway presence.

In this paper we present the hull design, sensor kit and technology stack for an autonomous boat. The boat uses a high definition camera and sensors to generate a detailed portrait of the river and intelligently control its steering dynamics.

The two major contributions of this paper are designing suitable control laws for the boat's steering control (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). *The business will make the bulk of its money selling a proprietary autonomous delivery system and its services to cities and business along the rivers.*

This paper is structured as follows:

Section II presents the hull design and sensor kit. Section III draws out the technology stack for the Riverway Awareness and and Warning System (RAWS). Section IV 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 customer facing business plan.

II. 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 less is best.

To establish the hull's design we use simulation software (Tripp_HullDesign) to guide the design of a low drag 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 kit with associated software (Tripp_Core, Tripp_Utils, Tripp_Launch). The boat's components are then married together with zip ties and epoxy thickened with wheat flour. Finally solar panels and thrusters are added to bring our proof of concept to life.

With the hull and body established we add our sensor kit with software drivers consisting of: (1) high definition color camera pointed forward and angled slightly downward for long range vision, (2) 2D LiDAR sensors pointed forward with different tilt angles for vision within 25 meters, (2) thermal radars for distances as far 200 meters, (1) sonar sensor for underwater obstacle detection and (1) Inertial Movement Unit sensor (IMU) which help the boat localize itself and its surroundings to centimeter level precision.

Fig. 1. Boat Design & Sensor Kit

III. RIVERWAY AWARENESS AND WARNING SYSTEM (RAWS)

Our technology stack, which goes by the name of RAWS generates a detailed image of the riverway. RAWS zeros in on optimizing arbitrary non-linear functions in robotics applications. Applications include: maximizing sensor kit absorption, minimizing energy consumption, computation of resting configuration and optimizing the boat's execution time for "Where am I? Where is everyone else? How do I get from A to B?"

The RAWS processing pipeline stretches across seven interconnected layers detailed in sections IV thru X.

Fig. 2. Technology Stack (aka RAWS)

IV. LOCALIZATION (USING HISTOGRAM FILTERS)

+ Where am I?

Construct a histogram filter and blend it with a real map to localize the boat's position, orientation and velocity using the GPS beacon. The histogram filters reflect the boat's understanding of its current location as a probability distribution. Measurement updates (i.e. sensing) use the Bayes Rule and motion updates (i.e. movement) use the Theorem of Probability.

— See Appendix B for Tripp_Localization

V. RIVERWAY PERCEPTION

+ Where is everyone else?

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

— Tripp_Vision

VI. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else?

Determine with certainty the location of others, especially moving obstacles using thermal radar, 2-D LIDAR, sonar. We represent the current state (e.g. position, orientation and velocity) as a vector and uncertainty as a covariance matrix.

— Tripp_Kalman, Tripp_Lidar, Tripp_Radar, Tripp_Sonar

VII. WAVE RUGGEDNESS INDEX

+ Where is everyone else?

Set maximum speed based on the shock imparted using IMU sensor

— Tripp_WaveRuggednessIndex

VIII. PATH PLANNER

Map (and guide) the boat's position, orientation and velocity along a pre-planned route by minimizing cost functions for action and terrain. We model the route as a connected graph with costs for traveling between nodes.

— Tripp_WaveRuggednessIndex

IX. BEHAVIORAL CLONING

Train a neural net to drive our autonomous boat like a human

— Tripp_BehavioralCloning

X. STEERING CONTROL

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

Send steering, throttle and brake commands to thrusters to autonomous boat using proportional-integral-derivative (PID) and a model predictive controller.

— Tripp_Autonomy

Fig. 3. Force Vectors on Boat

XI. FIELD TESTS & RESULTS

A. FIELD TESTING SETUP

Establishing repeatable environments for testing is paramount. Our testing ground stretches between the Goose Island Overlook (1100N) and the East Bank Club 571 (200N) along the North Branch of the Chicago River.

B. RESULTS

XII. DISCUSSION & FUTURE RESEARCH

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?
— What stylistic elements and geo-spatial patterns (i.e. the visual minutiae of daily urban and natural life) make Chicago's Rivers look like Chicago?

We run open water field tests in fog, rain, smoke and dynamic lighting to validate the efficiency and accuracy of the boat's collective algorithms.

Data from the field tests also 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 extends Professor Geoffrey Hinton et la.'s research to conceptualize a prefrontal cortex, whose dopamine based architecture stamps in associations between pixel-level sensor data flows. We believe this approach helps the boat better establish its own "rules of thumb" about how to safely navigate its preplanned routes with better consideration for scale, occlusion and viewing angles.

XIII. CUSTOMER FACING BUSINESS

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

Through the eyes of customers we're just another option for moving cargo/ people. Though what we do different is target city transportation's weaknesses — it's crowded, uncomfortable and un-hospitable during rush hour. We remedy this transportation problem with light heartened human personalities, comfortable seating and a shockingly smooth experience for cargo/people. Our goal is to be a front runner in the emerging riverway transportation experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

Our business was envisioned to reduce roadway congestion and help riverway communities quickly move cargo/people. We see Chicago's Riverways almost like a giant express lane slicing thru the city — a lane that's been empty far too long.

To validate the city's transportation 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, proximity to the river, method of transportation to river, race, 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.

We will make the bulk of our money selling a proprietary autonomous delivery system and its services to cities and business along the rivers. Our goal is to help make Chicago's Rivers another powerhouse mercantile and transportation hub of the city.

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

Fig. 4. Conceptual Renderings

D. MAKING THE REGISTER RING

We will make the bulk of our money selling a proprietary autonomous delivery system and its services to cities and business along the riverways.

Services include: (1) moving cargo for a flat rate (2) hospitably transporting people for a flat rate (3) offering buyouts for groups seeking a cannabis inspired tour of the river (4) selling goods abroad our boat.

E. WHAT MAKES US UNIQUE?

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

Our culture is rooted in empowering a group of self-confident entrepreneurs who will run these boats. To root out bureaucracy we rely heavily on human-computer symbiosis. 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. being 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 that meets the terms of the Paris Climate agreement. 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

Carl Doersch et la., "What Makes Paris Look like Paris?", ACM Transactions on Graphics, Article No.:101, July 2012

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

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

Sebastian Thurn et la., "Stanley: The Robot that won the DARPA Grand Challenge," 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," ,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	

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_ RiverLaneFinder

Tripp_KalmanFilter

Tripp_Lidar

Tripp_Radar

Tripp_WaveRuggednessIndex

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

Tripp_PathPlanning

Tripp_BehavioralCloning

Keras + Transfer Learning

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

Middleware