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

Michael Valentino Ochoa (LAST REVISION: 3/11/20)

I. MOTIVATION

Global sea level rise will be among one of the greatest challenges facing our society this century. Understanding how this phenomenon will reverberate onto riverway communities will require regular riverway presence. Our goal is to build an autonomous boat with a human ethnographer aboard to be that regular riverway presence.

II. INTRODUCTION

In this paper we document the hull design, sensor kit implementation and system architecture for an autonomous boat. The boat uses a high definition camera and sensor kit to generate a detailed portrait of the river. It then uses this data for autonomous lane keeping, obstacle detection, active cruise control and localizing its center of buoyancy. The second major contribution of this study is a customer facing business for this technology. Our plan blend old world traditions (Venetian Water Taxis) and the modern culture that characterizes Chicago (hospitality, delivery services and autonomy). The business will make the bulk of its money selling a proprietary autonomous delivery system and its services o communities and businesses along Chicago's Rivers. Generally speaking, the 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).

This paper is structured as follows:

Section III presents the hull design and sensor kit. Section IV unpacks system architecture 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 XI and Section XII gives way to the discussion. To conclude Section XIII presents the customer facing business plan.

III. HULL DESIGN & SENSOR KIT

To establish the hull's design we use simulation software (Tripp__HullDesign) to compute the "drag" on the boat and conceptualize a low wake hull form. To construct the hull (approximately 1:8) we laser cut marine grade plywood and couple it with 3D printed components. The hull houses the motor, battery and decoupler to form a watertight hatch, which is sealed and held in place over 2mm thick O-rings using bolts and wing nuts. The deck connecting the hulls is made for a to be determined material which tbd materials on its sides. Electronics are stored in a watertight "junction box" with a lid for easy troubleshooting. The box is L x W x H and contains the mini-computer, microcontroller, GPS kit , Wi-Fi, etc 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. The boat is powered bye a solar panel and batteries with wiring schematic and wiring diagram show in Figure 2B.

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 all together help the boat localize itself and its surroundings to centimeter level precision.

Fig. 1. Boat Design & Sensor Kit

IV. TECHNOLOGY STACK "RAWS"

Riverway Awareness Warning System (RAWS) is the name of our technology stack. It generates a detailed image of surrounding riverway terrain and triggers auditory and visual warning when the boat is in danger. RAWS zeros in on optimizing arbitrary non-linear functions in robotics applications. Applications include: maximizing sensor kit absorption and optimizing the boat's execution time for, "Where am I? Where is everyone else? How do I get from A to B?"

RAWS technology stack stretches across seven interconnected layers detailed in sections V thru XI. Lower layers interact with the sensor and actuators to produce desired positioning and tracking performance. While higher layers are used for maneuvering, error identification and error correction. By decoupling RAWS optimization problem across seven layers we make this big ol' arbitrary non-linear function more tractable.

Fig. 2A, 2B Technology Stack (aka RAWS) & Wiring Schematic

V. BOAT STATE ESTIMATION & LOCALIZATION

+ 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.

Tripp__LocalizationHistogram

VI. TERRAIN LABELING

+ Where is everyone else?

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

Tripp__RiverLaneFinder

VII. DEEPER ANALYSIS

+ Where is everyone else?

Determine with certainty the location of others with a Kalman Filter for accurate estimation of both static and dynamic obstacles

Tripp__KalmanFilter

VIII. WATER PROPERTY ESTIMATION

+ Where is everyone else?

Set maximum speed based on the shock imparted using IMU sensor, etc.

Tripp__WaveRuggednessIndex

IX. PATH PLANNER ("SMOOTHING")

Map the boat's position, orientation and velocity along a pre-planned route by minimizing cost functions for action and river conditions

Tripp__PathPlanner

X. BEHAVIORAL CLONING

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

Tripp__BehavioralCloning

XI. REAL TIME CONTROL OF THRUSTERS

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

Send steering, throttle and brake commands to boat's thrusters using proportional-integral-derivative (PID) and a model predictive controller. The goal is calculate an open loop optimal control problem and minimize a given objective function while respecting given constraints, and then repeatedly solving it to obtain dynamic feedback control laws.

Tripp__Autonomy

Fig. 3. Force Vectors on Boat

XII. FIELD TESTS & RESULTS

A. FIELD TESTING SETUP

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.

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. FIELD TESTS

C. ETHNOGRAPHIC NOTES

D. SAFETY TESTS

E. SUSTAINABILITY TESTS

XIII. DISCUSSION & FUTURE RESEARCH

In this paper, with the help of a human ethnographer, we extend the capacity of our autonomous boat to understand:

— Where am I?
— Where is everyone else?
— How do I get from A to B?
— What makes Chicago's Rivers look like Chicago?

The goal is to create a riverway experience that could impress both a transit safety and sustainability commissioner.

Future research will explore one of the more challenging problems in autonomous transportation — mapping the rivers, as they're big and they change constantly. Our research extends Professor Geoffrey Hinton's research and conceptualizes a prefrontal cortex for our boat. The goal is to help our autonomous boat ignore irrelevant details and ensure a tiny fraction of its computer vision is processed at the highest resolutions. Our dopamine based architecture stamps in associations between pixel level sensor data flows to achieve this. We believe our approach helps the boat better establish its own "rules of thumb" about how to safety navigate Chicago's Rivers.

Additional research aims to produce a compact "sensory storyboard" of the boat's daily sensor kit data that can be interpreted by a human viewer in seconds. This multi-sensory application of a summarization algorithm incorporates GPS data, time and pixel-level sensor data flows to provide deeper memory cues for our autonomous boat.

XIV. CUSTOMER FACING BUSINESS

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

Our customers are people/businesses who commute/move cargo along the river. We target Chicago riverway transportations problems — they're not nimble, they are transit deserts along the river and they could be more hospitable. We remedy the problem with an intimate experience, new transit riverway transit stop and light-hearted human personalities. Our goal is to be a from runner in the emerging riverway transpiration experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

To validate riverway transportations problem we developed a 16 item questionnaire to better understand people's perceptions, preferences and attitudes about having to walk to the river. Specifically, are people willing to restrict some liberties (i.e. the freedom of calling an "Uber") but it's done in order to advance larger ones (i.e. healthier cities)

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 decades the challenge focused on engineering, but as technology gets increasingly commodified trying to build leisure and hospitality services is uncertain, so we focus on engineering and software to build out our resilient transportation network affiliate services.

Our solution is a proprietary autonomous riverway delivery system for people and businesses along Chicago's Rivers. Our low wake low emission autonomous boat with human ethnographer/safety driver aboard will be available for 3 roundtrips in the AM, 3 roundtrips in the PM and riverside deliveries throughout the day. Riverway services will occur between the Julia C. Lathrop Homes (2800 N) and Park No. 571 (2800 S) along the North and South Branches of the Chicago River.

We sense a clear market opportunity on the river and strive to incite some newfound sociability around our boats. Our business is equal parts home-away-from-home on the river & roving trading post.

Fig. 4. Conceptual Rendering

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 dynamic priced 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 understands that the hospitality and autonomy worlds speak different languages. Until someone figures out how to bridge that gap, a full scale vertically integrated riverway transit service is not going to succeed.

I don't believe we're starting from a point of weakness, our knowledge of software and hospitality are solid. And we're working on engineering.

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 better meet the terms of the Paris Climate agreement. Our vision is not necessarily the answer, but rather a step in a creative learning process towards healthier cities :)

G. POLICY MEMORANDUM

Expanding riverway transit will bring about both negative and positive change. A well designed program should be able to make riverway transit a sustainable backbone for future urban growth. Ways to encourage this could include using rising property taxes in corridors along the river as a financing toolbox to fund future riverside infrastructure needs.

XV. 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.

Yong Jae Lee and Kristen Graumann, "Predicting Importing Objects for Egocentric Video Summarization" Journal of Computer Vision (IJCV), January 2015

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 / SONAR	
Capture Frequency	
Operating Frequency	
Range	
Bandwidth	

Bill of Materials

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

APPENDIX B

Design Files | File Type (CAD)

Fin.DXF

BatteryHolderBack.DXF

BatteryHolderFront.DXF

BatteryHolderPlate.DXF

CircuitBoardSpace.DXF

LiDARMountingBottom.DXF

LiDARMountingPillar.DXF

MotorBracket.DXF

HatchBottomLayer.DXF

HatchLid.DXF

HatchMiddleLayer.DXF

HatchTop.DXF

HullSectionCutsBack.DXF

HullSectionCutsFront.DXF

ElectronicPlateForJunctionBox.DXF

APPENDIX C

Operation Instructions

APPENDIX D

Software Packages

Tripp__LocalizationHistogram

Tripp__RiverLaneFinder

Tripp__KalmanFilter

Tripp__WaveRuggednessIndex

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

Tripp__PathPlanning

Tripp__BehavioralCloning

Tripp__Autonomy

Establishes suitable control laws for the boat's thrusters on which collective algorithms for steering angle, throttling and braking can be assessed based on conditions and task

Tripp__Core

Manages sensors, low communication and actuators

Tripp__Utils

Utility scripts for commanding boat from manual override from laptop, configuration files and installer scripts

Tripp__Launch

Expedites task setup by calling packages with configurations

Point__Cloud__Lib

Formatting and processing toolkit for point cloud data

Drivers for Sensors

Robot Operating System (ROS)

High level processing and middleware for robot software development that supports linux

Tripp__HullDesign

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