What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/16/20)

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 a regular riverway presence. The goal of our autonomous boat with human safety driver is to be that regular riverway presence.

II. INTRODUCTION

In this paper we document the hull design, sensor kit 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 portrait to guide its autonomous lane keeping, obstacle detection, active cruise control and localization of its center of buoyancy. The second major contribution of this study is a customer facing business (and policy memorandum) for this technology. Our business plan blends old world traditions (Venetian Water Taxis) and the modern culture that characterizes Chicago (hospitality and delivery services). Our business will make the bulk of its money selling a proprietary autonomous riverway transportation system and its services to 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 hospitable animals that we are).

This paper is structured as follows:

Section III describes the hull design and sensor kit. Section IV unpacks the system architecture for the Riverway Awareness and and Warning System (RAWS). Section V thru XI explain RAWS in greater detail. Field testing and results are unraveled in Section XII and Section XII gives way to the discussion and future research. To conclude Section XIIV presents the customer facing business plan.

III. HULL DESIGN & SENSOR PROCESSING AND INTEGRATION

To establish the hull's design we use simulation software (Tripp__HullDesign) to compute the "drag" on the boat and conceptualize an efficient 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 within 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 using a "to be determined material". 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 is powered by a solar panel and batteries with its wiring schematic and wiring diagram shown in Appendix E.

With the hull and deck established we add our sensor kit 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, (1) audio sensor and (1) Inertial Movement Unit sensor (IMU) to measure wave ruggedness. All together the sensor kit helps the boat localize itself and its surroundings to centimeter level precision.

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.

The goal is of RAWS is not to build a library of events. Its goal is to extract the core principles that makes boats safely drive. RAWS aims to bring more diversity to the learning of these core principles so it can better behave properly when new situations arise.

Fig. 1. Boat Design & Sensor Kit

Fig. 2A. Technology Stack (aka RAWS)

V. SIMULTANEOUS LOCALIZATION AND MAPPING (SLAM)

+ 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__SLAM

VI. MOTION PLANNING

+ Where is everyone else?

Determine the location of riverway "lanes" and other static obstacles using the boat's front facing camera

Tripp__RiverLaneFinder

VII. SCENE UNDERSTANDING

+ Where is everyone else?

Determine with certainty the location of others with a Kalman Filter for accurate estimation of both static and dynamic obstacles using a combination of LiDAR, Radar, Sonar and Camera data as necessitated

Tripp__KalmanFilter

VIII. WATER PROPERTY ESTIMATION

+ Where is everyone else?

Set maximum speed based on the shock imparted using IMU sensor data and the kinematic and dynamic limitations of the boat

Tripp__WaveRuggednessIndex

IX. MISSION PLANNER

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

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

Compute the cost (as a function of time and risk) of the pre-planned route thru the world given knowledge of riverway conditons. The mission planner reasons about the optimal path much a human would

Tripp__PathPlanner

X. 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. Our boat will require a good reward function that balances safety and enjoyment, this is what Tripp_Autonomy strives to discover.

Tripp__Autonomy

XI. BEHAVIORAL CLONING

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

Tripp__BehavioralCloning

Fig. 3. Force Vectors on Boat

XII. INTEGRATION, TESTING & RESULTS

A. FIELD TESTING SETUP

We run open water field tests in fog, rain, exhaust, shadows, reflections, snow 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 across four loops stretching 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 safety driver, 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?

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

Future research will explore some 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. This prefrontal cortex's dopamine based architecture stamps in associations between patterns in pixel level sensor data. The goal is to help our autonomous boat ignore irrelevant details and ensure fractions of its vision is processed at the highest resolutions. 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.

Finally our autonomous boat will be better designed to act with the speed and agility to defend its services against cyberattacks. Future research takes steps to shore of our cybersecurity capabilities to ensure the safety of the riverside communities we serve.

XIV. CUSTOMER FACING BUSINESS

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

Our customers are communities living along the river. Our business targets Chicago's biggest riverway transportation problems — it's not nimble, they are transit deserts and it could be more hospitable. We remedy the problem with an intimate experience, new riverway services and our light-hearted human personalities. Our goal is to be a front runner in the emerging riverway transportation experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

To validate riverway transportations problem we developed a 16 item questionnaire to better understand people's attitudes and preferences about having to walk to the river for services. Specifically, are people willing to restrict some liberties (i.e. the rise of on-demand services and directly-to-the-door delivery options) in order to advance larger ones (i.e. less emissions, healthier cities, etc.)

Our survey was tested on 32 respondents across different ages, their proximity to the river, their 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 resilient transportation network services is the new challenge.

Our solution is a proprietary autonomous riverway transportation system for communities and businesses along Chicago's Rivers. Our low wake low emission autonomous boat 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 hope to incite some newfound sociability around our services. We see our business as equal parts home-away-from-home on the river & roving trading post.

Fig. 4. Conceptual Rendering

D. MAKING THE REGISTER RING

We derive revenue from the licensing of our intellectual property (i.e. our proprietary autonomous transportation system for data acquisition, data labeling, data storage and data management and our services: (1) moving cargo for a dynamically priced rate (2) hospitably transporting people for a dynamically priced rate (3) offering buyouts for groups seeking a cannabis inspired tour of the river (4) selling foodstuffs and staple goods abroad our boat. Additionally our riverway business and recommendation website serves as guide to riverside products and services. The website will generate revenue by offering direct links to riverside merchants in exchange for a portion off the sale price upon completion of a transaction, which we will record as other revenues.

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. We aim to bridge the gap. We don't believe our business is starting from a point of weakness, our knowledge of software and hospitality is solid, and we're working on engineering.

We're aware we operate in a highly competitive environment. We compete for business along a specific geographic corridor, and new competitors can quickly emerge. Our ability to compete effectively depends on many factors both within and beyond our control. Our success depends on our ability to respond and adapt to changes in technology and consumer behavior. We will continue invest significant resources to mitigate these potential risks and build, maintain and evolve our business. These investments may adversely impact us in the short term, but it will ensure our long term sustainability and vitality.

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

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		
Audio Sensor		
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__SLAM

Tripp__RiverLaneFinder

Tripp__KalmanFilter

Tripp__WaveRuggednessIndex

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__Launch

Expedites task setup by calling packages with configurations

Tripp__Utils

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

Point__Cloud__Lib

Formatting and processing toolkit for point cloud data

Drivers for Sensors

Robot Operating System (ROS)

Logging data, error handling and communications framework

ROS Nodes

Splits high level tasks into low level ones and creates a Unix thread for each of them (i.e. perception, decision making, actuation)

Tripp__HullDesign

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

APPENDIX E

Wiring Schematic and Diagram