

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 delivery 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 XIV 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 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 Figure 2B.

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 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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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, 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

+ How do I get from A to B?

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

Fig. 3. Force Vectors on Boat

XII. FIELD TESTS & 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.

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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 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?

The goal is to create a human-centered autonomous boat 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 fractions of its computer vision is processed at the highest resolutions. We believe our approach helps the boat better establish its own "rules of thumb" about how to safely 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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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 people/businesses who commute/move cargo along the river. We target Chicago riverway biggest transportations problems — its not nimble, they are transit deserts along the river and it could all 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 front 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 for services. Specifically, are people willing to restrict some liberties (i.e. the freedom of calling an "Uber") in order to advance larger ones (i.e. healthier cities, less emissions, etc.)

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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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 also 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 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 hope to incite some newfound sociability around our services. The 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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

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.		

**What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using
Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)**

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

What Makes Chicago's Rivers Look Like Chicago? An Ethnographic Study Using Human-Centered Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/13/20)

APPENDIX D

Software Packages

Tripp__LocalizationHistogram

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.