What Makes Chicago's Waterways Look Like Chicago? An Ethnographic Study Using Autonomous Boats | Michael Valentino Ochoa (LAST REVISION: 3/18/20)

I. MOTIVATION

Global sea level rise will be among one of many challenges facing our society this century. Understanding how this phenomenon will reverberate onto these communities will require a regular presence. The goal of our autonomous boats is to be that regular resilient waterway presence for communities.

II. INTRODUCTION

In this paper we document how the autonomous boat works and ways to use the boats. We do this first by unpacking the boat's hull design, sensor kit and technology stack. We share how to use the boat by writing a business plan (and policy memorandum). Our business blends old world traditions (i.e. Venetian Water Taxis) and the modern culture that characterizes Chicago (i.e. transportation, hospitality, packaged goods). It makes money selling its proprietary autonomous waterway transportation system and services to communities and businesses along waterways. Generally speaking, we let autonomous boats do what they do best (e.g. lane keeping, obstacle detection, active cruise control) and let humans aboard the boats do what we do best (e.g. be the clever animals that we are).

This paper is structured as follows: Section III describes the hull design and sensor kit. Section IV unspools the technology stack for the Water Awareness and and Warning System (WAWS). Section V thru X explain WAWS in greater detail. Field testing and results are unpacked in Section XI and Section XII gives way to the discussion and future research. To conclude Section XII describes our customer facing business plan.

III. HULL DESIGN & SENSOR KIT 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) Hydrophone 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 "WAWS"

Water Awareness Warning System (WAWS) is the name of our technology stack. It generates a detailed image of surrounding waterway 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 X. 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. Hull 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 boat's GPS beacon.* The histogram filters reflect the boat's understanding of its current location as a probability distribution

Tripp__SLAM

VI. MOTION PLANNING

+ <u>Where is everyone else?</u>

— determine the location of waterway "lanes" and other static obstacles *using the boat's front facing camera*

Tripp__LaneFinder

VII. SCENE UNDERSTANDING

+ <u>Where is everyone else?</u>

— 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*

Tripp__KalmanFilter

VIII. WATER PROPERTY ESTIMATION

+ <u>Where is everyone else?</u>

— set maximum speed based on the shock imparted *using boat's IMU sensor and based on 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 water conditions. the cost of the pre-planned route is a function of time and risk given knowledge of waterway conditions and necessitated action. **the mission planner reasons about the most eco-friendly routing scheme for the real time control of the boat's thrusters**

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. **the control laws built alongside a neural net that learns to drive our autonomous boat like its human safety driver.** Ultimately building an objective function that balances safety, efficiency and enjoyment.

Tripp__Autonomy
Tripp__BehavioralCloning

Fig. 3. Force Vectors on Boat

XI. INTEGRATION, SETUP / TEARDOWN & FIELD TESTS

We run open water field tests in fog, rain, exhaust, reflections and changing lighting to validate the efficiency and accuracy of the autonomous boat's collective algorithms. Data from the field tests also helps the boat proactively improve its practices for lane keeping, obstacle avoidance, active cruise control and localizing its center of buoyancy.

Establishing repeatable environments for testing is essential as we've yet to include changes in mass to our boat's testing. Fields tests occur in Chicago's Humboldt Park Lagoon.

A. FIELD TESTS

B. ETHNOGRAPHIC NOTES

C. SAFETY TESTS

D. SUSTAINABILITY TESTS

XII. 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 waterways, 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 establish its own "rules of thumb" about how to safety navigate Chicago's waterways in a way that is less computationally intensive for its onboard computer. .

Additional research will takes steps to shore up our cybersecurity capabilities to further ensure the safety of the waterway communities we serve.

XIII. CUSTOMER FACING BUSINESS

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

Our customers are communities and businesses along waterways. We bring low cost effective water transportation services to them at low costs. By blending hospitality with autonomous transit our business better creates trust and acceptance in this new market. It also helps us solve the problem of scoping out, identifying and integrating with third parties because they'll familiar with our presence on the water. We reduce environment costs by optimizing the flow of goods and people along waterways. The goal is to be a front runner in the emerging waterway transportation experience.

B. HOW HAVE WE VALIDATED THE PROBLEM?

To validate the idea that optimizing the flow of goods along riverway is a good idea we developed a 16 item questionnaire. The questionnaire sought to better understand people's attitudes and preferences about waterways. Specifically, we were curious whether waterway communities were willing to restrict some liberties (i.e. not having to leave their home) in order to advance larger ones (i.e. walking to a waterway for services to reduce carbon emissions, healthier cities).

Our survey was tested on 32 respondents across different ages, distance-to-waterway, method of transportation to that waterway, age and general level of activity.

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 has become the new challenge.

Our solution is a proprietary autonomous waterway transportation system for communities and businesses along Chicago's waterways. Our low wake low emission autonomous boat will be available for 3 roundtrips in the AM, 3 roundtrips in the PM and waterway deliveries throughout the day. Waterway 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 water and hope to incite some newfound sociability around our transportation services. We see our business as equal parts home-away-from-home on the water & roving trading post.

Fig. 4. Conceptual Rendering

D. MAKING THE REGISTER RING

We derive revenue from (1) licensing our intellectual property, a proprietary autonomous transportation system for data acquisition, data labeling, data storage and data management (2) moving cargo at sliding rate (3) hospitable water taxi rides at sliding rate (4) offering buyouts for groups seeking a cannabis inspired waterway tour (4) selling packaged goods abroad our autonomous boat.

Marketing efforts are be driven by our waterway business and recommendation website. The website will serve as guide to businesses and services near the waterways. The website will generate revenue by offering direct links to businesses featured in exchange for a portion of theirs sales 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 vertically integrated waterway transportation service will not thrive. We strive to bridge this gap.

We don't believe our business is starting from a point of weakness, our as 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 will quickly emerge.

Thought we are ready for the challenge. We embrace business — the competition, the environmental challenges and the camaraderie.

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

REFERENCES

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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		
Hydrophone		
Mini Computer		
Micro Controller		
Wifi Adapter		
Thrusters		
Solar Panel		
Boat Hull Design, etc.		

APPENDIX B

Design Library

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

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APPENDIX C

Mission Checklist

Inspect hull, sensor kit, field equipment

Wake up energy source, etc.

Activate laptop

Initiate contact with boat

Sync laptop / phone to same network

Connect phone to boat computer

Run "roscore" on local machine

Start TrippServer with local machine

Check debug app

Check for "rostopics" on local server

Start GUI on local machine

Connect to localhost

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…

…

APPENDIX D

Software Packages (in no order)

Tripp__SLAM

Tripp__LaneFinder

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.

TrippServer