Establishing Autonomy on Chicago's Riverway Using Computational Approaches

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I. INTRODUCTION

In this paper we present the boat design, sensor kit and technology stack for an autonomous boat. The goal is for the boat to interpret data above and below the riverway in a way similar to how humans use their senses to relate to the world around them. (e.g. Where am I? Where is everyone else? How do I get from A to B?).

The two main contributions of this paper are to design suitable control laws for four predictive thrusters, on which collective algorithms for obstacle detection, lane keeping and active cruise control can be assessed. The second contribution is a customer facing business that builds positive feedback loops along the riverway by blending old world traditions (Venetian water taxis) and the modern culture that characterizes Chicago (hospitality and autonomous technology).

II. 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 can be that regular riverway presence.

This paper is laid out at follows. Section III presents the design, fabrication and bill of materials for the boat and sensor kit. Section IV draws out the technology stack for the Riverway Awareness and and Warning System (RAWS). *Section V thru X describe RAWS in greater detail.* Field testing setup and results are unpacked in Section XI, and Section XII gives way to the discussion. To conclude Section XIII presents the customer facing business.

III. BOAT HULL & SENSOR KIT

Our prototype is rectangular shaped with the dimensions being approximately (0.9m x 0.45m x 0.1m). We laser cut marine grade plywood and 3D print various components to fabricate the hull as its proven to be a swift, solid and low cost method for prototyping. The hull's design is inspired by the "architectural ornaments" of Louis Sullivan. The pieces are then married together by zip ties, epoxy thickened with wheat flour, and several layers of fiberglass. Next, a mini computer, micro controller, wifi adapter, mobile beacon, four omni-directional thrusters and solar panel are added to the boat.

Fig. 1. Boat Design & Sensor Kit

Finally, our sensor kit is added to teach the boat to interpret the world around them in a way that is similar to the way human drivers use their senses to relate to the world around them. The sensor kit is made up of: (1) color camera, (2) 2D LiDAR sensors, (2) 24 GHz radar sensors, (1) sonar sensor and (1) Inertial Movement Unit (IMU) sensor which allow the boat to localize itself in urban rivers to sub-centimeter level precision.

Item	Price	Weight
Color Camera		
(2) LIDAR		
(2) Radar		
Sonar		
IMU Sensor		
Mini Computer		
Micro Controller		
Wifi Adapter		
Mobile Beacon		
4 Thrusters	$500	
Solar Panel	$180	
Boat Hull, etc.		

IV. *RIVERWAY AWARENESS AND WARNING SYSTEM (RAWS)*

Sensors //

Perception //

Planning & Control //

User Interface for Human Driver //

Global Services //

Our technology stack interprets sensor data to control four predictive thrusters, on which collective algorithms for obstacle detection, lane keeping and active cruise control can be assessed

A non-linear differential equation models the language of physics occurring on the water. The goal is to drive the error of selected variables to zero for a preplanned open water route. The differential equation model decouples the optimization problem into approximately 20 modules across six interconnected layers detailed in sections V thru XI.

V. *BOAT STATE ESTIMATION*

+ Where am I?

Inputs >>

Position (GPS)
Velocity
Orientation (IMU)

Fig. 2. Boat Inputs

1. Boat Velocity
2. Kinematic equation relating velocity in inertial to those in body frame.
3. Transformation matrix converting state vector from body to inertial frame.

4. Decouple mass matrix with added mass matrix and vehicle mass sum
5. Rigid body matrix of corollas and centripetal terms and the added mass matrix with consideration for origin and center mass
6. Semi-definite drag matrix represented by linear dampening
7. Applied force and moment vector
    1. Control matrix describing thruster configuration
    2. Control vector, difference between transverse and longitudinal propellers
8. State Vector of Boat
9. Dynamic Model of Boat

VI. RIVERWAY PERCEPTION

+ Where is everyone else?

For short and medium range obstacle avoidance up to 30m in front.

VII. DEEPER RIVERWAY PERCEPTION

+ Where is everyone else (cont.) ?

VIII.WATER PROPERTY ESTIMATION

+ How do I get from A to B?

Establishing riverway boundaries and the wave ruggedness index.

IX. PATH PLANNING

+ How do I get from A to B?

X. THRUSTERS ALGORITHM

+ How do I get from A to B?

+ Velocity
+ Steering

Once the intended path of the boat has been established by the path planner, the most efficient throttle, brake and steering commands are committed with respect to minimizing the lat & long trajectory planning error along the pre-planned route. Generally speaking the goal is to design suitable control laws for the four thrusters and drive the errors of selected variables to zero.

XI. FIELD TESTS & RESULTS

A. FIELD TEST SETUP

+ East Bank Club > Weed St Boathouse
+ River Use Characteristics
+ Perception of River
+ Local Demographics

Fig. 3. Map of Testing Grounds

B. BOAT STATE ESTIMATION

C. RIVERWAY PERCEPTION

D. DEEPER RIVERWAY PERCEPTION

E. WATER PROPERTY ESTIMATION

F. PATH PLANNING

G. THRUSTERS ALGORITHM

H. SAFETY TESTING

XII. DISCUSSION & FUTURE WORK

In the paper we extend the capacity of an autonomous driving system to understand:

— Where am I?
— Where is everyone else?
— How do I get from A to B?

We run open water field tests in fog, smoke and rain to validate the efficiency and accuracy of (RAWS) and our thrusters algorithm. The field tests provide data that the boat uses to proactively improve its autonomous safety practices.

In the future, our work will explore the following topics. First, showing how "gut feelings" could be channeled into machine language that helps autonomous riverway systems better formulate problems and test their own intuitions. By conceptualizing a prefrontal cortex whose dopamine based architecture "stamps-in" association between inputs using mental rules, concepts and analogies. The goal is to give the system an intrinsic motivation to play across its data inputs to better learn which data to hold onto in its "mind", formulate problems, imagine solutions and explain its behavior.

Second, our research will continue exploring how changing mass and drag effect the thruster algorithm when transporting people and goods. Third, better rationing materials, especially metal and delving into alternative durable materials. And finally, creating an experience piloted by our smart driving system that could impress both a safety and sustainability commissioner.

XIII. CUSTOMER FACING BUSINESS

We recognize there is an immense amount of noise in the autonomous transit industry. For years the challenge focused on engineering, but as autonomous technology becomes increasingly commodified, trying to work out how to build services in a new regulatory environment will be the next challenge.

By targeting public transit's weaknesses — an uncomfortable and sometimes inhospitable image — a clever startup with the right strategy, the right message and the right product could create a new riverway transit brand for the new decade.

Our business is focused on being public transit that prepares people to take on the city, a kind home-away-from-home on the river. We feel this approach best positions our business for contract work with autonomy giants, etc. We believe in letting water our autonomous system do what it does best (e.g. obstacle detection, lane keeping and active cruise control) and letting humans aboard the boats do what we do best (e.g. be the social and hospitable animals we are).

At a time when our generation faces ecological, economic and values crises, some of the most essential technology in navigating the path ahead is not the autonomous system we outlined above. A future governed by rationality and science offers no space in these times, there's just too many social and environmental tradeoffs needed to meet the aspirations of our wonderfully diverse humanity. Our vision of autonomous transit on the river may not be the answer, but rather a step in a creative learning process.

XIV. REFERENCES

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