~~Establishing L2+ Level Autonomy for the Riverway Using Computational Approaches~~

I. ABSTRACT

In this paper, we present the design, sensor kit and processing pipeline for a hybrid system of water robotaxi and human safety driver. Generally speaking, we are extending the capacity of the system to understand: Where am I? Where is everyone else? And how do I get from A to B? Our sensor kit absorbs the world above and below the riverway to formulate a dynamic model. Based on this model the robotaxi establishes suitable control laws for four predictive thrusters by solving an open-loop optimal control problem. The systems's goal is to learn suitable thruster control laws for: lane keeping, active cruise control, trajectory tracking and obstacle avoidance. We believe a human safety driver combined with the rational analytics of a water robotaxi establishes L2+ level autonomy.

II. WHAT IS THE PROBLEM?

As Earth's cities become filled with smog and traffic jams new solutions must surface to solve our global transit challenge. Existing infrastructure cannot support another generation of gas guzzling vehicles. The lost time, wasted fuel and climbing costs of doing business are not sustainable. We must begin chipping away at this collective problem.

III. HOW DO WE SOLVE THIS PROBLEM?

To leapfrog some of this archaic transit paradigms established we draw upon engineering, hospitality and urban economics.

We deploy a hybrid system made of up of a robotaxi and human safety driver to chip away at the problem. The hybrid system blend the rational analytics of a computer integrating inertial, optical and thermal data with human strategic guidance. We believe in letting machines do what they do best (lane keeping, active cruise control, trajectory tracking and obstacle avoidance) and letting humans do what we do best (be the social and hospitable animals that we are). Our narrow focus on blending this L2+ level autonomous system with hospitality means our transit does more provide convenience, it's a space that prepares you to take on the city — a kind of home-away-from-home on the river.

IV. PROTOTYPE DESIGN & FABRICATION

Our scale model (approximately 1:8) system:

— Rendering 1

A rectangular shape was chosen to accommodate two horseshoe shaped seating booths present in future iterations. Our prototype is approximately .9m x .45m x .1m. We 3D print the hull as its proven to be a swift, solid and low cost method for prototyping. We fabricate the hull from 16 separate pieces (inspired by the "architectural ornaments" of Louis Sullivan to bring the material to life). The pieces are then married together by bolts, plastic O-rings and several layers of fiberglass. Next we add a warning light, horn and leak sensor with additional safety updates to follow.

— Costing Table 1

V. SENSOR KIT (AKA "WATERWAY WHISKERS")

To ensure the real-time performance of lane keeping, active cruise control, trajectory tracking and obstacle avoidance along a pre-planned open water routes our system uses a Gigabyte Mini PC (Intel Core i7-6500U) with 32 GB of memory running Ubuntu 16.04 as the main controller. While a 32-bit micro-controller gathers GPS and IMU data and sends it to a processing pipeline that fine tunes the control action of thrusters. The drive mode is guided by four thrusters and the power supply a solar panel. Diversified sensors, including GPS, IMU, thermal radar, depth camera and voltage sensor are also installed onboard. All together the hybrid system runs on the Robotic Operating System (ROS) and a human safety driver that sits idle at the helm of a manual override switch.

— Isometric View

— Costing Table 2

VI. BOAT DYNAMICS ESTIMATION

Following in the footstep of other academics the current state estimation can be generally described by a non-linear differential equation. By reformatting the estimation as a grey-box model with unknown hydrodynamic parameters we convert the system into a giant optimization problem.

VII. WATER PROPERTY ESTIMATION

VIII. PROCESSING PIPELINE: TRAJECTORY TRACKING

IX. PROCESSING PIPELINE: CONTROL ACTION OF THRUSTERS

The control architecture consists of multiple layers that decouple the optimization problem and make the problem tractable. The lower layers interact with the "whisker kit" to interpret desired position and tracking performance. While the higher layers are used for maneuver coordination, fault identification and tracking performance. Our three layer control architecture considers both discrete and continuous time. The first layer is a human supervisory layer (that minimizes energy consumption, assist with manual override for tricker maneuvers and safety, etc.). Additional layers include a coordination layer (for safe execution of basic maneuvers and event management) and a stability layer (that interfaces directly with the hardware and contains the dynamic model, sensor data processing, fault detection monitoring as well as signaling changes in environmental conditions).

Generally speaking, the processing pipeline outlined in Section VII & XI involve two sliding surfaces. The first defines the desired vessel position and and orientation and the second layer defines the thruster velocity needed to drive the robotaxi along the preplanned route.

X. FIELD TESTS & RESULTS

A. FIELD TESTING SETUP

B. RESULTS: PARAMETER ID

C. RESULTS: TRAJECTORY TRACKING

D. SAFETY TESTING

XI. CUSTOMER FACING BUSINESS

We recognize there is an immense amount of noise in the autonomous transit industry, so we aim to master the things we understand. Our narrow focus is on pairing hospitable service with L2+ level autonomous robotaxis specialized to run on Chicago's rivers.

We believe this best positions our business for contract work with autonomy giants, simulation services, etc. By constraining our technology problem to Chicago's rivers we target an environment that has a clear and distinct need for mobility. We start simple with a few transit stops and delivery services for communities along the North Branch of the Chicago River. Our belief is that by starting simple we can speed up our ability to expand and outmaneuver bigger rivals as the autonomous transit industry shifts from perfecting its systems to finding the ideal business case.

— Conceptual Rendering

— Prototype Photograph

XII. CONCLUSION & FUTURE

The paper presents the body design, "waterway whisker" kit and processing pipeline for L2+ level autonomy. Our proof of concept is easy to manufacture, less than $2000 and capable of: lane keeping, active cruise control, trajectory tracking and obstacle avoidance in open water environments. We run field tests to validate the efficiency and accuracy of the proposed thruster strategy, which will be essential for accomplishing more advanced autonomy tasks.

In the future, our research will explore multiple topic. First, better acknowledging how thrusters handle changing mass on drag brought on by transporting people and goods along the riverway. Second, better addressing the wave disturbances that exist on the open water. Third, establishing a latching system that enables boats to link and join with each other and riverway docks. Our goal is to create an experience piloted by hybrid system that is so comfortable that it could impress a safety commissioner.

XIV. APPENDIX: POLICY MEMORANDUM

We are seeing the ways in which a lot of business behavior that is technically legal but not acceptable in terms of its impact, there has to be a higher standard. We propose a tax on autonomous services along the riverway within a downtown zone between 6a - 10p. We must establish how the profits that accrue from increasing automation will redirected back into society to benefit riverway communities. If we're serious about addressing climate inequities we need to listen more to riverway communities and co-create solutions rather than dictate them.

— Michael Valentino Ochoa

XII. REFERENCES

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