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 goal of the hybrid system 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 global problem.

III. HOW DO WE SOLVE THIS PROBLEM?

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

We deploy a hybrid system made of up of a robotaxi and human safety driver to chip away at the global problem. The hybrid system blend the rational analytics of a computer integrating inertial, optical and thermal data with a human safety driver to guide the water robotaxi.

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 a L2+ level autonomous system with hospitality means our transit does more than 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 1:6) 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 40 watt 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 who sits idle at the helm of a manual override switch.

— Isometric View

— Costing Table 2

VI. BOAT DYNAMICS ESTIMATION

Following in the footsteps 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 can convert the system into a giant optimization problem.

(1) Vehicle velocity in body fixed frame

(2) Kinematic equation relating velocity in inertial to those body frame

(3) Transformation matrix converting state vector to inertial frame

(4) Decoupled mass matrix with added mass matrix and vehicle sum mass

(5) Rigid body matrix and the added mass matrix with consideration for origin and center mass

(6) Drag matrix represented by line dampening

(7) Applied force and moment vector + Control matrix describing thruster configuration

(8) State vector of water robotaxi

(9) Reformulated grey-box model with unknown hydrodynamic parameters (mass & drag)

(10) …

— Elevation View 1

— Isometric View 2

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 more easily tractable. Our multiple layer architecture considers both discrete and continuous time. The lower layers interact directly with the "whisker kit" hardware for dynamic positioning, thruster allocation strategy, sensor data processing and fault detection monitoring. Whereas, the middle layers are used for the safe execution of basic maneuvers. While the highest layer is a human supervisory layer that minimizes energy consumption, assist with manual override for tricker maneuvers and safety, etc.

Generally speaking, the processing pipeline involves two sliding surfaces. The first defines the desired vessel position 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 IDENTIFICATION

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 lets 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 starting simple with a few transit stops and delivery services for along the a section of the Chicago River 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 an L2+ level autonomous system. Our proof of concept is easy to manufacture, less than $#### 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 topics.

First, better acknowledging how our four thrusters handle the changing mass and 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.

— Michael Valentino Ochoa

XIV. APPENDIX: POLICY MEMORANDUM

We must establish how the profits that accrue from increasing automation will redirected back into society. We are seeing the ways in which a lot of business behavior that is technically legal, but not acceptable in terms of its impact. We believe there has to be a higher standard. We propose a tax on autonomous services along the riverway within a downtown zone between 6am - 10pm.

XII. REFERENCES

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