Establishing L2+ Level Autonomy for the Riverway Using Computational Approaches

By Michael Valentino Ochoa (Updated: 12/27/19)

I. ABSTRACT

In this paper, we present the design, sensor kit and processing pipeline for a L2+ level autonomous water robotaxi with human safety driver. Generally speaking, we are extending the capacity of the hybrid 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 dynamic 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 the future belongs to the people who can best partner and collaborate with computers. Our goal is to combine a human safety driver with the rational analytics of a water robotaxi to establish L2+ level autonomy.

II. WHAT IS THE MOTIVATION?

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 number of hours we've lost to traffic delay, the costs of gridlock and fuel wasted in stalled traffic are not sustainable. We must begin chipping away at this global problem.

III. HOW DO WE SOLVE THIS PROBLEM?

To leapfrog some of our archaic transit paradigms we draw upon engineering, hospitality and architecture. The idea is to take something new, with good design and engineering behind it. We're still relying on ancient dirty tech and the clock in ticking on gasoline. We have to evolve.

We deploy a hybrid system made of up of a L2+ autonomous water robotaxi and human safety driver to chip away at this global problem. The hybrid system blends the rational analytics of a computer integrating inertial, optical and thermal data with the human strategic guidance of judgment, intuition, empathy and a moral compass. Our goal is optimize the collaboration between the two.

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 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 home-away-from-home on the river.

IV. PROTOTYPE DESIGN & FABRICATION (HULL)

The shape of the hull impacts the water robotaxis risk for capsizing in choppy conditions and its thrusters setup may also affect its maneuverability. While catamaran shaped hulls may make boats speedy and steady in rough waters, but it negatively sets the boat up for the omni-directional maneuvers needed in urban waterway scenarios such as docking and latching.

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.

Item	Price	Weight
RGB-D Camera	$177	
IMU Sensor		
LIDAR		
GPS		
Thermal Camera		
Mini Computer		
Micro Controller		
Wifi Adapter		
Mobile Beacon		
4 Thrusters		
Solar Panel		
Hull, etc.		
Warning Light		
Horn		
Leak Sensor		

V. HARDWARE (SENSORS, ELECTRONICS & THRUSTERS)

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.

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To make its way thru urban waterways the boat localizes itself with centimeter level precision. To achieve this our sensor kit relies on LIDAR, IMU, GPS, RGB-D camera and thermal camera. The sixteen beam LIDAR measures the relative position of obstacles within the sensors range, and it coupled with Euclidean clustering and contour tracking algorithms for accurate estimation of static and dynamic obstacles. The IMU sensor collects 3 axis (sway, yaw, surge) angular velocity data. Both data pipelines are then filtered thru an extended kalman filter. With this data the main controller can leverage this localization to follow a preplanned route. An RGB-D camera, thermal camera and GPS are mounted on the boat as well and used as secondary sensors.

— Isometric View

— Costing Table 2

VI. BOAT DYNAMICS

Following in the footsteps of other academics the problem 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)

VII. PROCESSING PIPELINE: PERCEPTION

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 let's 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/return services along sections of the Chicago River we can better outmaneuver bigger rivals as the autonomous transit industry shifts from perfecting its systems to finding the ideal local business cases. We believe the next phase of the digital revolution will come from businesses that link beauty to engineering and hospitable service to running code.

— Conceptual Rendering

XII. CONCLUSION & FUTURE

The paper presents the body design, hardware and software 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 is essential for accomplishing more advanced autonomy tasks. Our goal is to create an experience piloted by hybrid system that is so comfortable that it could impress a safety commissioner.

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. And finally, documenting the system architecture, design and requirements needed for a teleoperation kit that control multiple water robotaxis with one human safety driver operating a joystick from a distance.

XIIV. SOFTWARE PACKAGES

A. Perception

ada_autonomy: filters LIDAR data based on environment and task

ada_core: manages sensors, low-level communications and actuators

ada_launch: expedites task setup by calling packages with configurations

ada_localization: localizes boat with LIDAR, IMU, thermal and camera data. Manages EKF filtering and visual odometry.

ada_utils: utility scripts for commanding boat from manual override joystick from laptop, configuration files and installer scripts

point cloud lib (pcl): formatting and processing toolkit for point cloud data

drivers for LIDAR, IMU, RGB-D camera

B. Trajectory Optimization

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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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