Human-in-the-Loop Cyber Physical Systems: Modular Designs for Semi-Autonomous Wheelchair Navigation

AUTHORS: Ross Desmond, Matt Dickerman, James Fleming

ADVISOR: Taskin Padir, **CO-ADVISORS:** Sonia Chernova, Jerome Schaufeld, Dmitry Sinyukov

ABSTRACT

This project involves the design and development of a prototyping platform and open design framework for a semi-autonomous wheelchair to realize a human-in-the-loop cyber physical system (HiLCPS) as an assistive technology. The system is designed to assist physically locked-in individuals in navigating indoor environments through the use of modular sensor, communication, and control designs. This enables the user to share control with the wheelchair and allows the system to operate semi-autonomously with human-in-the-loop. The Wheelchair Add-on Modules (WAMs) developed for use in this project are platform-independent. These modules facilitate development and application of semi-autonomous functionalities. By using the WAMs, a team of three can convert similar powered wheelchairs into a semi-autonomous mobility platform in less than ninety minutes.

Project Overview

Wheelchair Add-on Modules (WAMs)

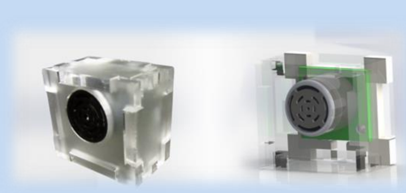
Footplate Sensor Protector: Places the sensors in strategic locations in front of the wheelchair while protecting them from damage.

Wheel-on-wheel (WOW) Encoder: Allows for a high friction wheel to directly measure rotation of the chair wheels. Provides a mounting solution to gather encoder data without being attached to wheel shaft.

Headrest Sensor Mount: Provides area for mounting additional sensor hardware surrounding the headrest . Includes internal wire management and mounts for swapping in custom sensor plates.

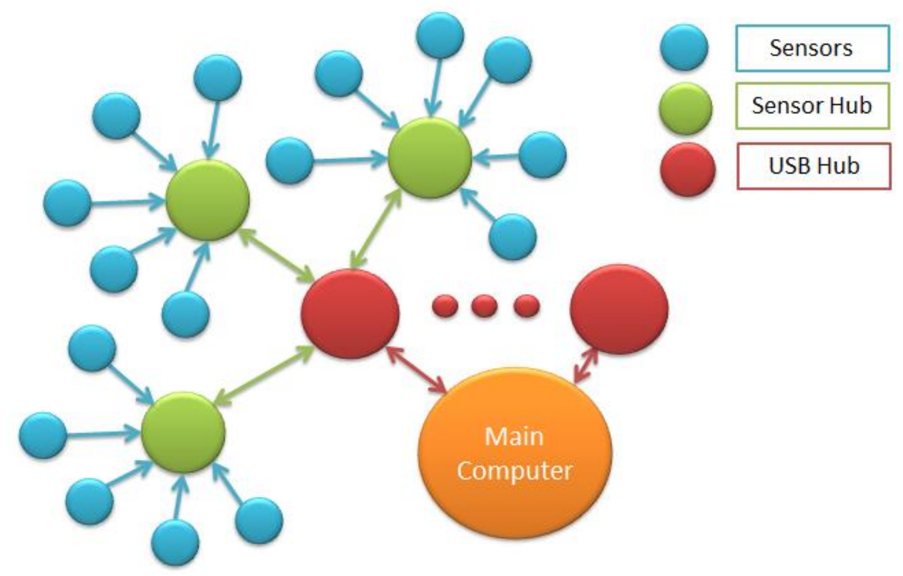
WAMNet Sensor Hub: A routing module which allows communication from low level sensor hardware to high level computer. Designed for easy replacement of key parts and sensors. Communication module has a unique ID used by WAMNet to identify the sensor hub.

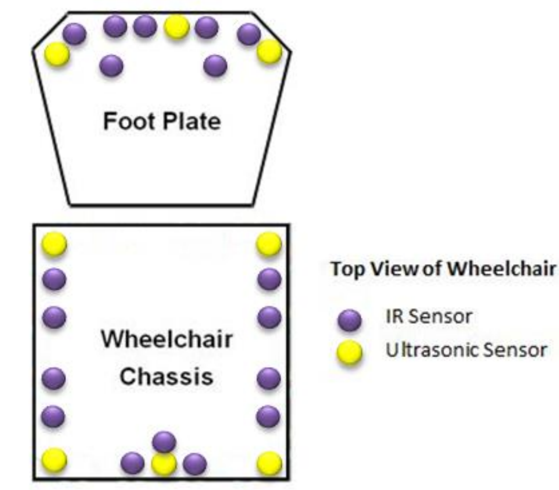
WAMNet Sensor Mounts: Custom built for IR and Ultrasonic sensors, these cases are mounted by VHB and help protect the sensor from damage.



LiDAR and IMU Holder: This case contains a spherical joint, allowing the IMU and LiDAR to be adjusted in three degrees of freedom. It locks on to the old joystick mount of an electric wheelchair.

Sensor Network (WAMNet)

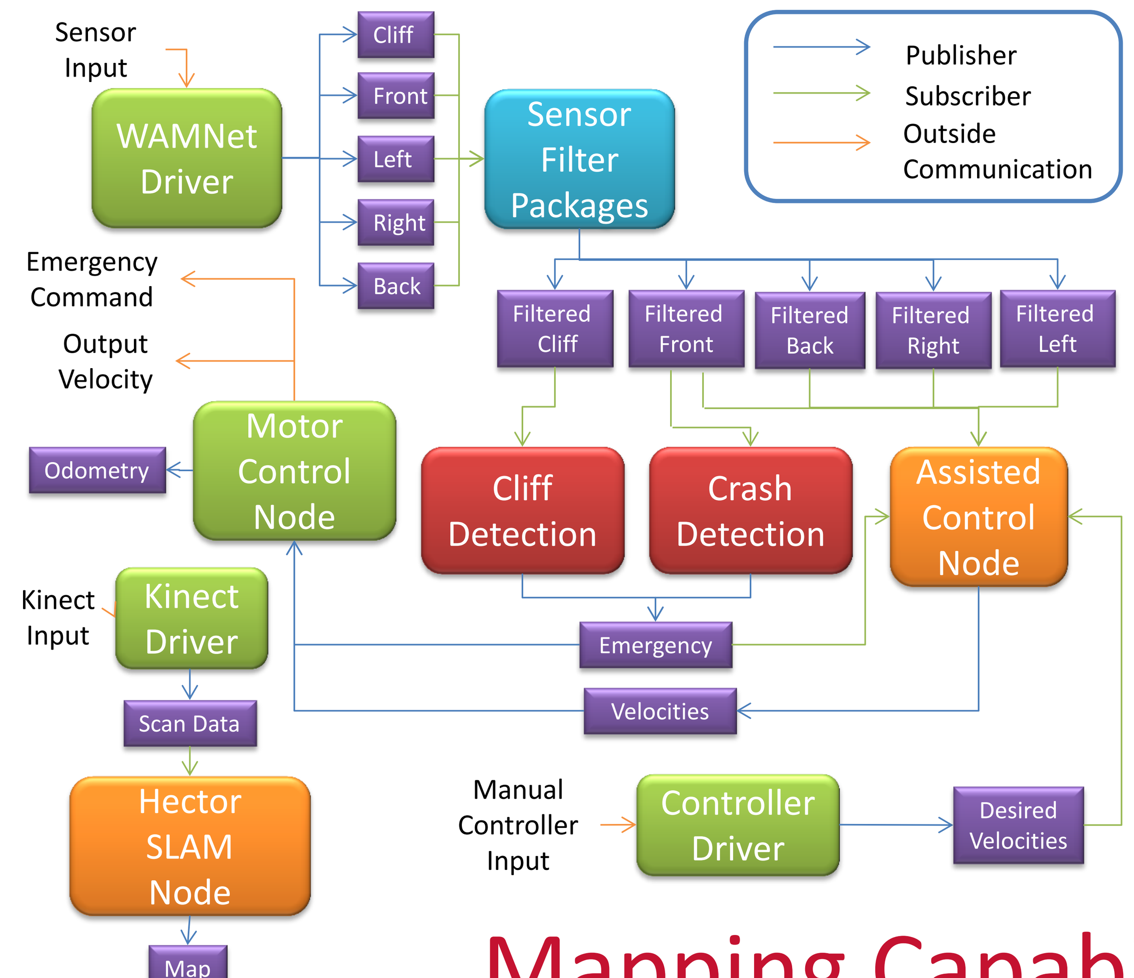




WAMNet Specifications

Interface	USB	
Sensors per Hub	Max: Two 3.3V, Four 5V	
Transmission Speed	CPS: 82 Hz per sensor *(for 7 hubs)*	
Number of Hubs	CPS: 7 Maximum: 127	
Communication with Hubs	Individual basis	
Communication	Serial at 115200 Baud	
Power Options	External 5 Volt or USB Power	
Number of Sensors on Project	8 Ultrasonic, 18 IR	Total: 26
Maximum Number of Sensors	Max 3.3V: 254, Max 5V: 508	Total: 762

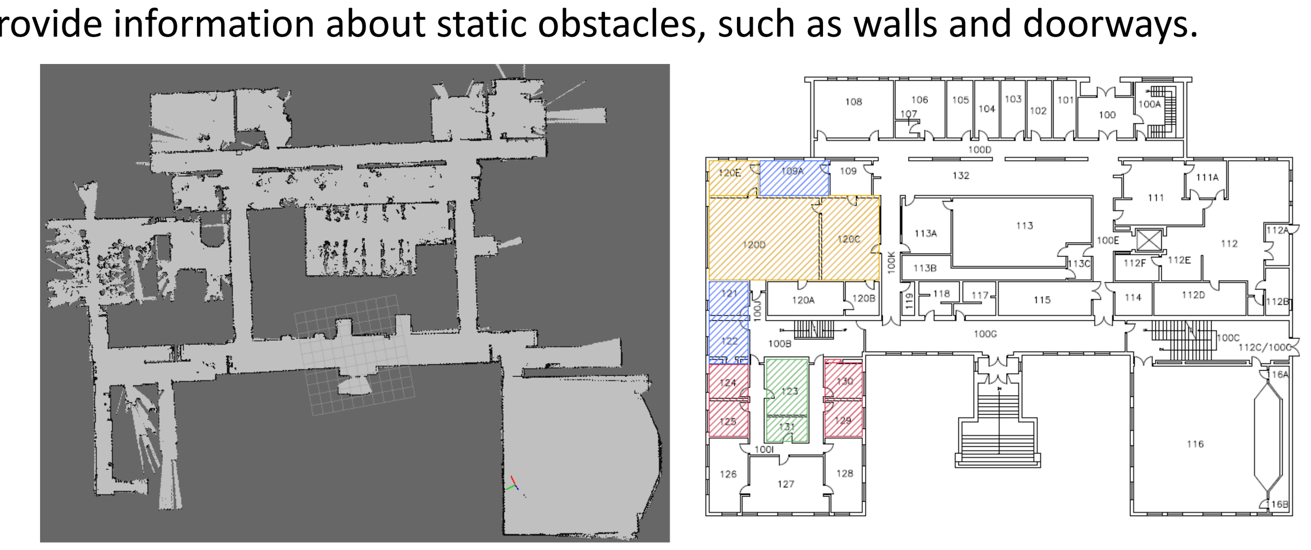
ROS Drivers for WAMNET and Controls



- Robot Operating System (ROS) architecture.
- Nodes can publish and/or subscribe to topics which transfer data.
- Driver nodes interpret data and/or drive outputs.
- Basic decision nodes such as cliff detection contain simpler logic and can bypass high level nodes in emergencies.
- High level nodes subscribe to interpreted data and make advanced decisions such as assisted control and mapping.

Mapping Capabilities

- Higher levels of semi-autonomy that involve path planning can utilize maps of the environment.
- Maps provide information about static obstacles, such as walls and doorways.

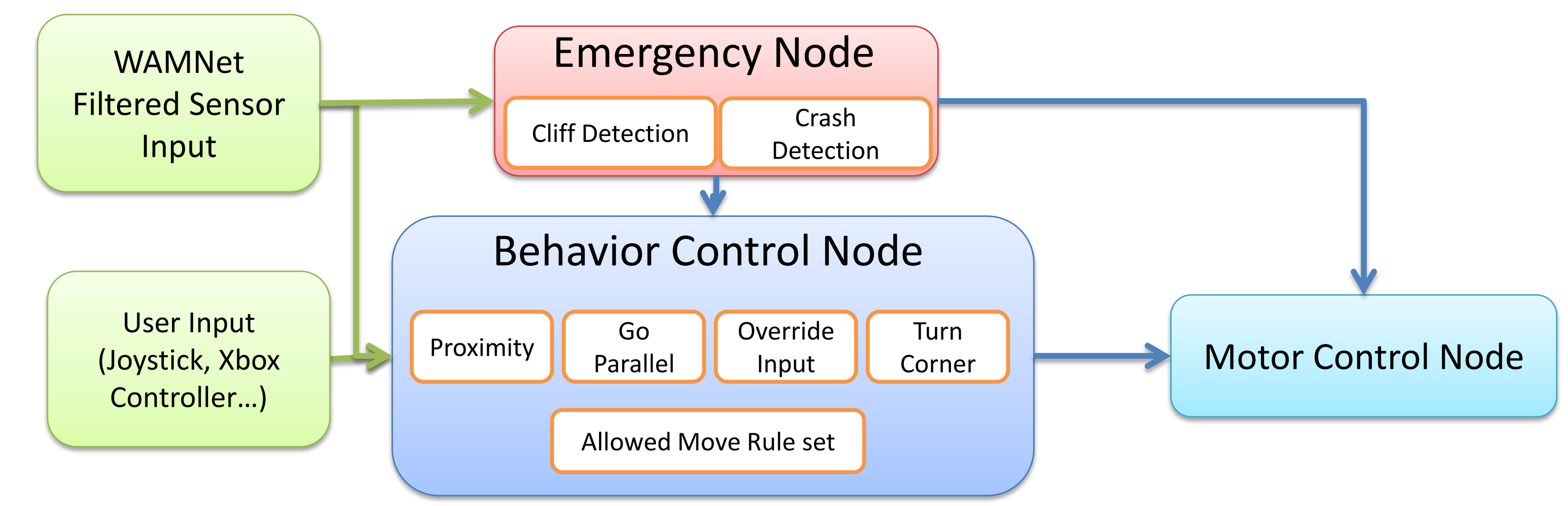


The example map (above left) that was generated from the LiDAR and IMU module is compared to an actual floor map of the same area (above right). The system uses Hector SLAM for mapping and localization, which can also be achieved using the Microsoft Kinect.

Operator Assisted Control

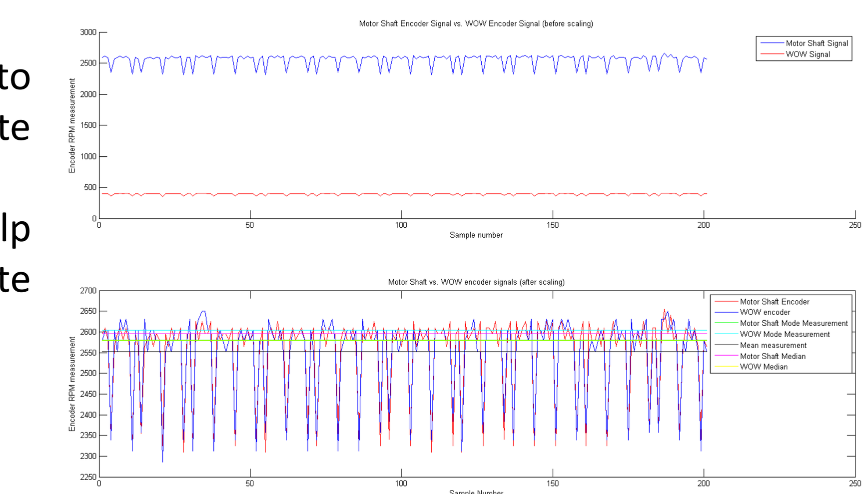
Behavior based control assistance for manual driving

- Utilizes the WAMNet to make reaction time decisions based on low level sensor input.
- Decreases velocity based on proximity to and velocity of obstacles.
- Attempts to keep parallel to walls and tangent to objects.
- Emergency Node reacts to cliffs such as stairs, and crash detection



Systems Engineering and Tests

- Used systems engineering principles to outline stakeholders, and generate requirements and tests.
- Used project requirements to help determine design specifications and create use cases.
- Tests validate objectives such as reliability.



Sample tests developed for validation:

- Power line test determines the suitability of the 5V power rail to power the WAMNet Sensor Hubs.
- Sensor communication test determines the expected reliability of computer-WAMNet communication.
- Encoder stability test (graph above) shows output of WOW encoders compared to motor shaft encoders. The outputs of both encoders were found to be equivalent.

Results

- LiDAR/IMU configurable to three degrees of freedom
- Headrest mount reconfigurable
- IR and Ultrasonic Case easily and securely mountable
- Footplate protects sensors from crashes
- Wheel-on-Wheel Encoder stable and reconfigurable
- Power line stability verified, with the note that simple filtering be done on 5V devices
- Sensor board communication reliability to less than one error per ten million bytes
- Behavior: Wall detection and tracking
- Behavior: Front/rear obstacle detection and collision avoidance
- Emergent Behavior: Assisted navigation through doorways
- Emergency Stops: Cliff and collision detection

Project Sponsors

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Publications

R. Desmond, M. Dickerman, J. Fleming, T. Padir, D. Sinyukov, J. Schaufeld, "Development of Modular Sensors for Semi- Autonomous Wheelchairs," Proc. 2013 IEEE International Conference on Technologies for Practical Robot Applications (TePRA), Boston, MA, April 22-23, 2013.

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- Cambridge Science Festival - Robot Zoo
- IEEE 5th Annual TePRA Conference
- Cornell Cup USA, presented by Intel