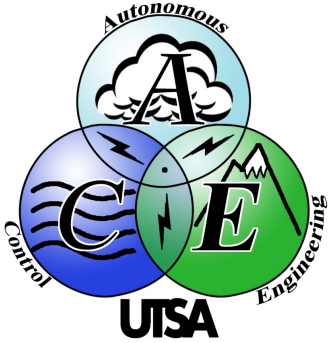
Design of a Home Multi-Robot System for the Elderly and Disabled

PATRICK BENAVIDEZ



Overview

Introduction

Proposed Home Robotic System

Software and Simulation Environment

Hardware

Summary of Contributions and Completed Work

Future Work

Introduction

Demand is only increasing for assistive robots

- Japan, Europe, Korea and the US all have age-related population problems that can be helped by assistive robots
- The Robotics and Automation Society states that important research projects have been recently launched in ***Europe, Japan and Korea***. The ***US is not even listed as a key player*** in the research. [*http://www.ieee-ras.org/rehabilitation-robotics*]
- Conferences: *IEEE International Conference on Rehabilitation Robotics* (**ICORR**) –2013 attendance: 340, *IEEE Technologies for Practical Robot Applications* (**TePRA**), *The Rehabilitation Engineering and Assistive Technology Society of North America* (**RESNA**) partners with ICORR
- Regular IEEE Spectrum e-articles asking "where are our home robots?"

Introduction

Demand is increasing for assistive robots (cont.)

- **RoboCup** added an **@Home** event described as ***"largest international annual competition for autonomous service robots and is part of the RoboCup initiative"*** [http://www.robocup.org/robocup-home/]

Introduction (cont.)

Multiple robots and effect on task space

- Existing robot systems work in their own environment
  - Roomba works as if it is the only robot in a room
  - Task spaces are assumed to be the entire area
  - Simple sensor beacons are used to control robots
- Task space could be split up into parts
  - Make execution of task more efficient
  - Robots can build sophisticated maps of the environment for navigation – could be used to partition

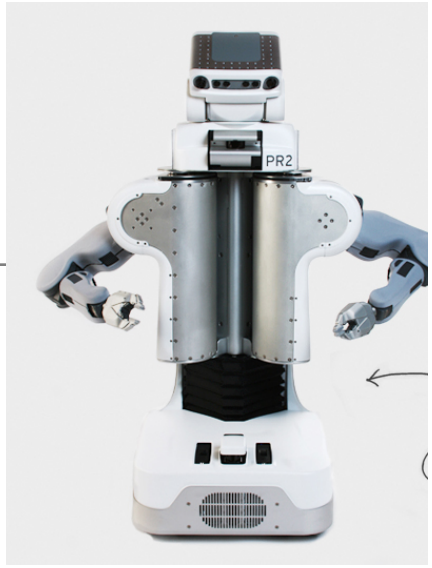
http://en.wikipedia.org/wiki/File:Roomba_time-lapse.jpg

https://www.youtube.com/watch?v=S7plVfRA2jQ#t=48

Introduction (cont.)

Networked and Cloud Robotics

- WillowGarage decided to make things easier for researchers with ROS and PR-2 showpiece
- Unbounded Robotics was formed by former WillowGarage employees have their UBR-1 ~$35k



Cost: ~$330k

Criticized by AARP for being too slow at folding towels and very expensive

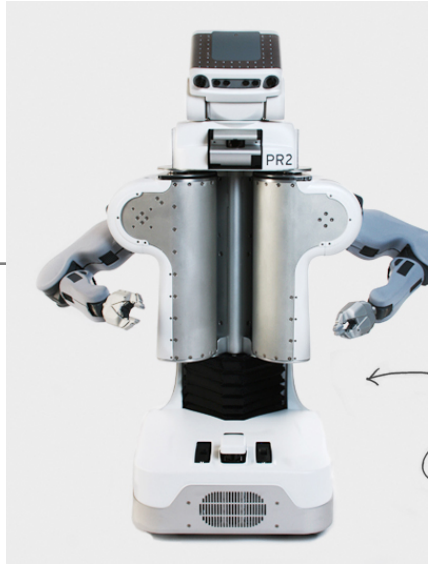
http://unboundedrobotics.com/ubr-1/

http://www.willowgarage.com/pages/pr2/overview

Introduction (cont.)

Networked and Cloud Robotics

- WillowGarage decided to make things easier for researchers with ROS and PR-2 showpiece
- Unbounded Robotics was formed by former WillowGarage employees have their UBR-1 ~$35k
- Unfortunately for Unbounded Robotics, the UBR-1 was *bound* to fail due to derivative work clauses in the former employee's contracts



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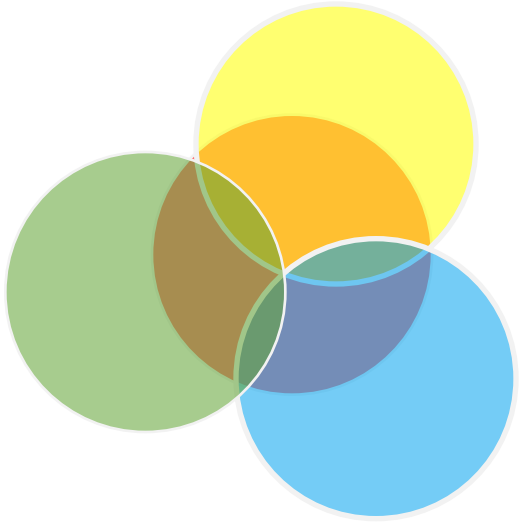
Proposed Home Robot System

Proposed Home Robot System

The proposed system is designed with the following top level goals:

- Provide an application set to suit the general needs of user population
- Develop the system to be extensible and configurable
- Partition task space for heterogeneous robots

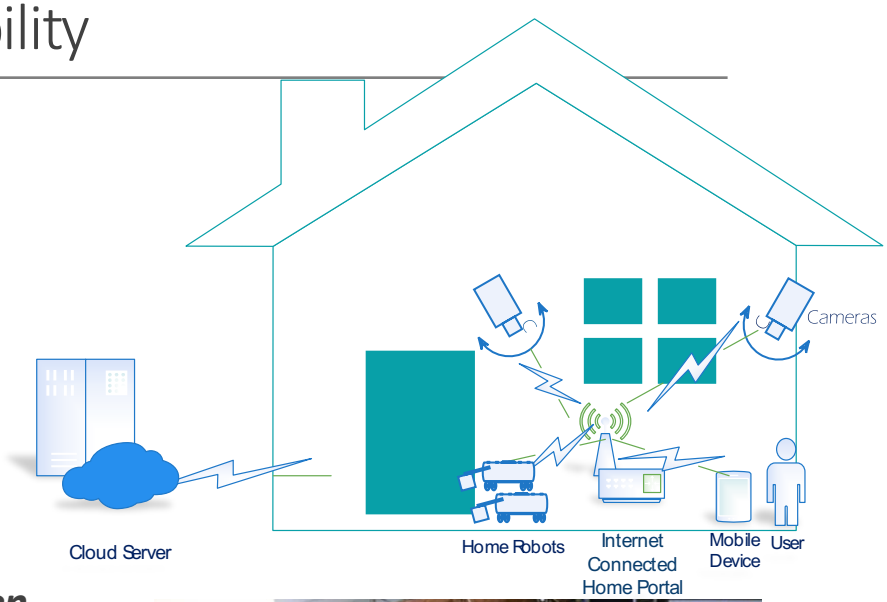


Proposed Home Robot System

System Extensibility & Configurability

The following principles are proposed to extend the usefulness of the system:

- ***Use of cloud computing technology*** to *provide data processing support* and to *allow expansion of services*
- Provide a set of ***standards allowing cooperative robot control*** in system
- Openness to ***allow application (app) driven control of robots*** in system
- ***Integration with existing equipment*** such as security systems and cameras, or "smart" IoT devices

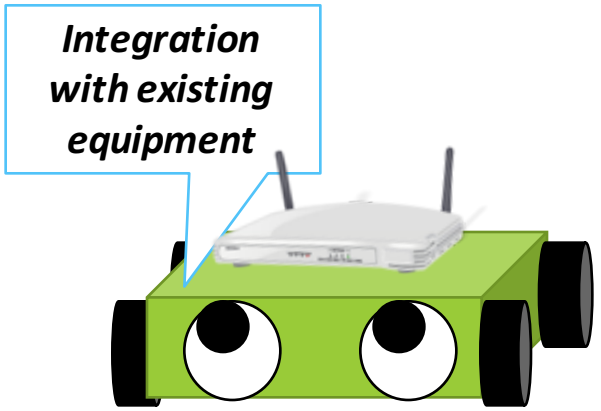


Photographer: Deborah Silliman Wolfe

Proposed Home Robot System

System Extensibility & Configurability (Cont.)

How to manage all this in the home?

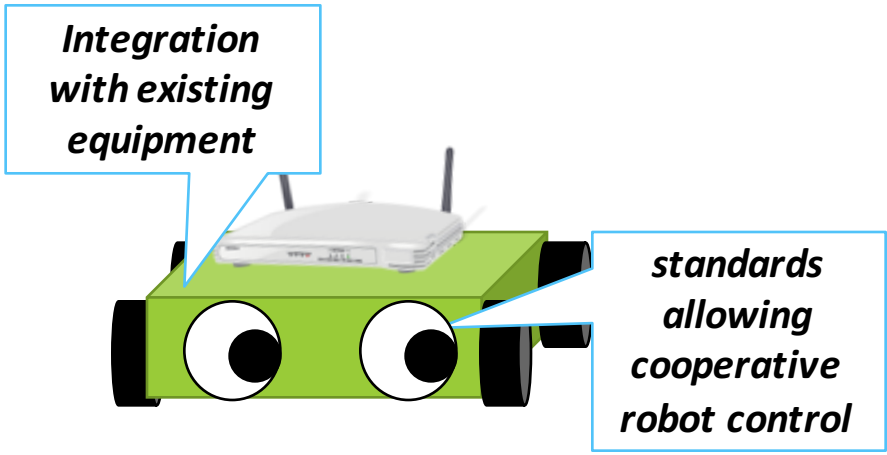


Cloud Back End

Proposed Home Robot System

System Extensibility & Configurability (Cont.)

How to manage all this in the home?



Cloud Back End

Proposed Home Robot System

System Extensibility & Configurability (Cont.)

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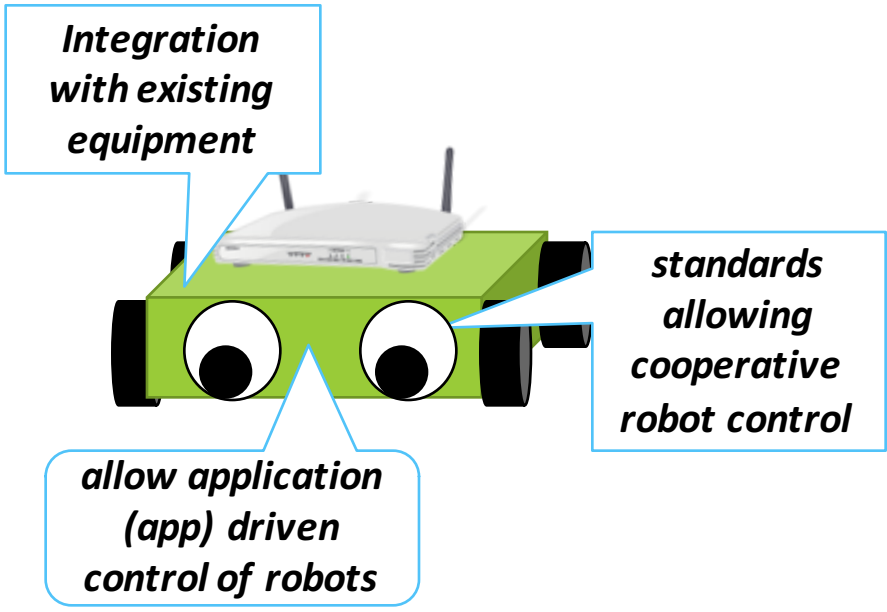

Cloud Back End

Proposed Home Robot System

System Extensibility & Configurability (Cont.)

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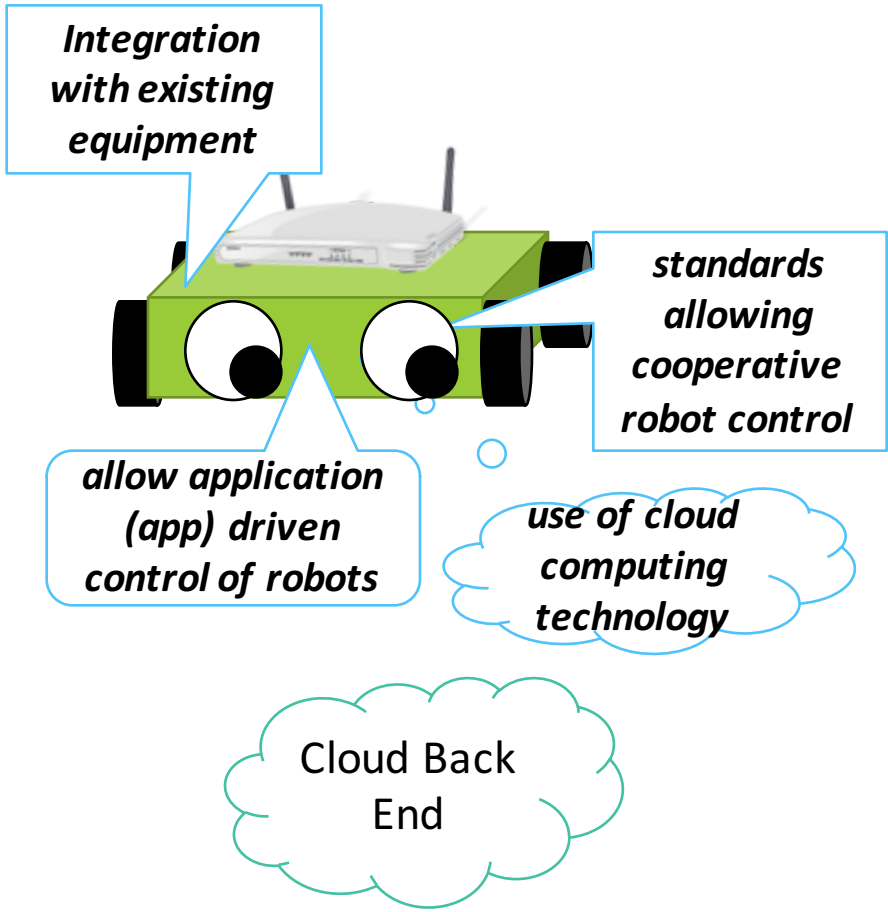

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System Extensibility & Configurability (Cont.)

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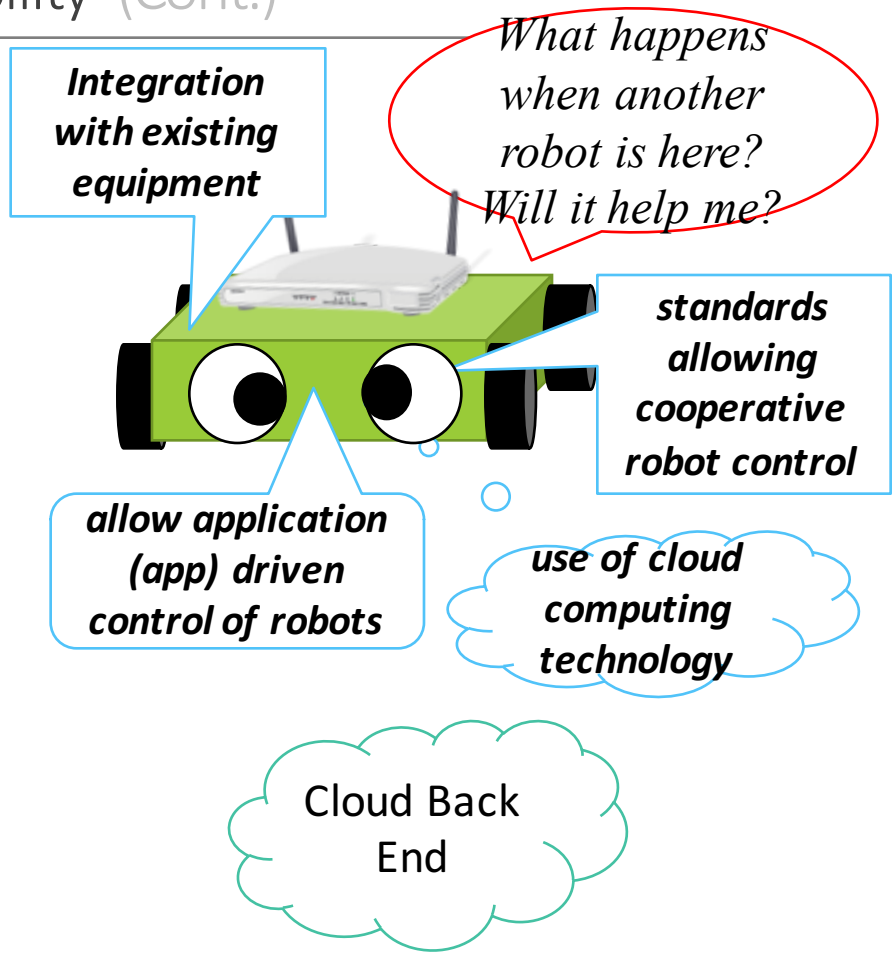
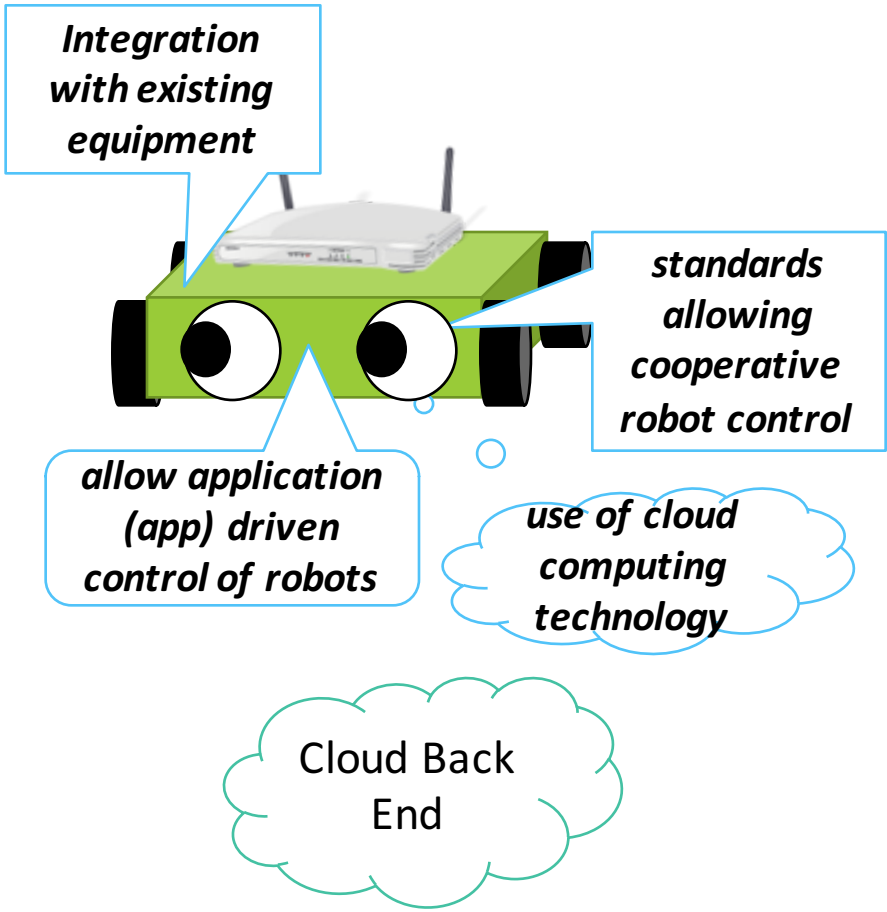


Proposed Home Robot System

System Extensibility & Configurability (Cont.)

How to manage all this in the home?

- Use of ***open-source Robot Operating System (ROS) middleware***
  - Provides a common API for process-to-process and machine-to-machine communication
  - Provides instructions and some API to access system via non-ROS applications such as “apps” on a mobile device
  - Drivers can be made for existing or legacy equipment

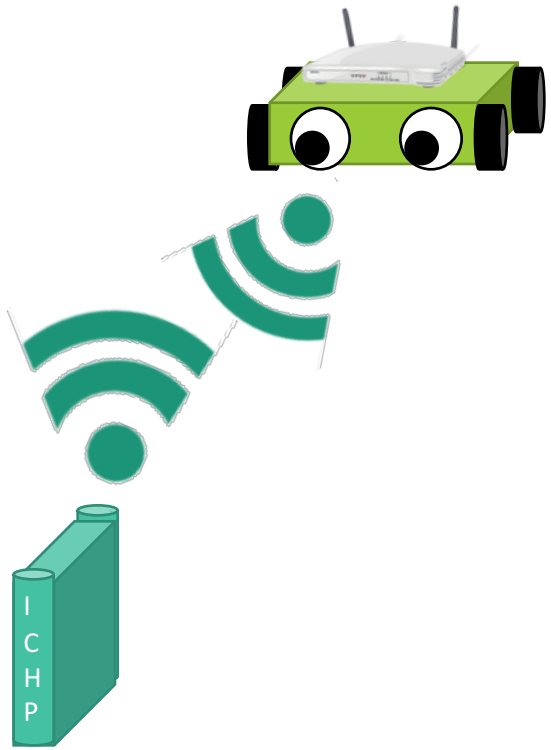


Proposed Home Robot System

System Extensibility & Configurability (Cont.)

How to manage all this in the home?

- Offload a portion of the work to the **Internet Connected Home Portal** (ICHP) and to the **cloud**
  - Device can be similar in form to a *wireless router* or *cable internet modem*
  - Maintains high bandwidth connections to robots
  - Provides intermediary link between N robots and cloud computing
  - Integrates with existing "smart" components



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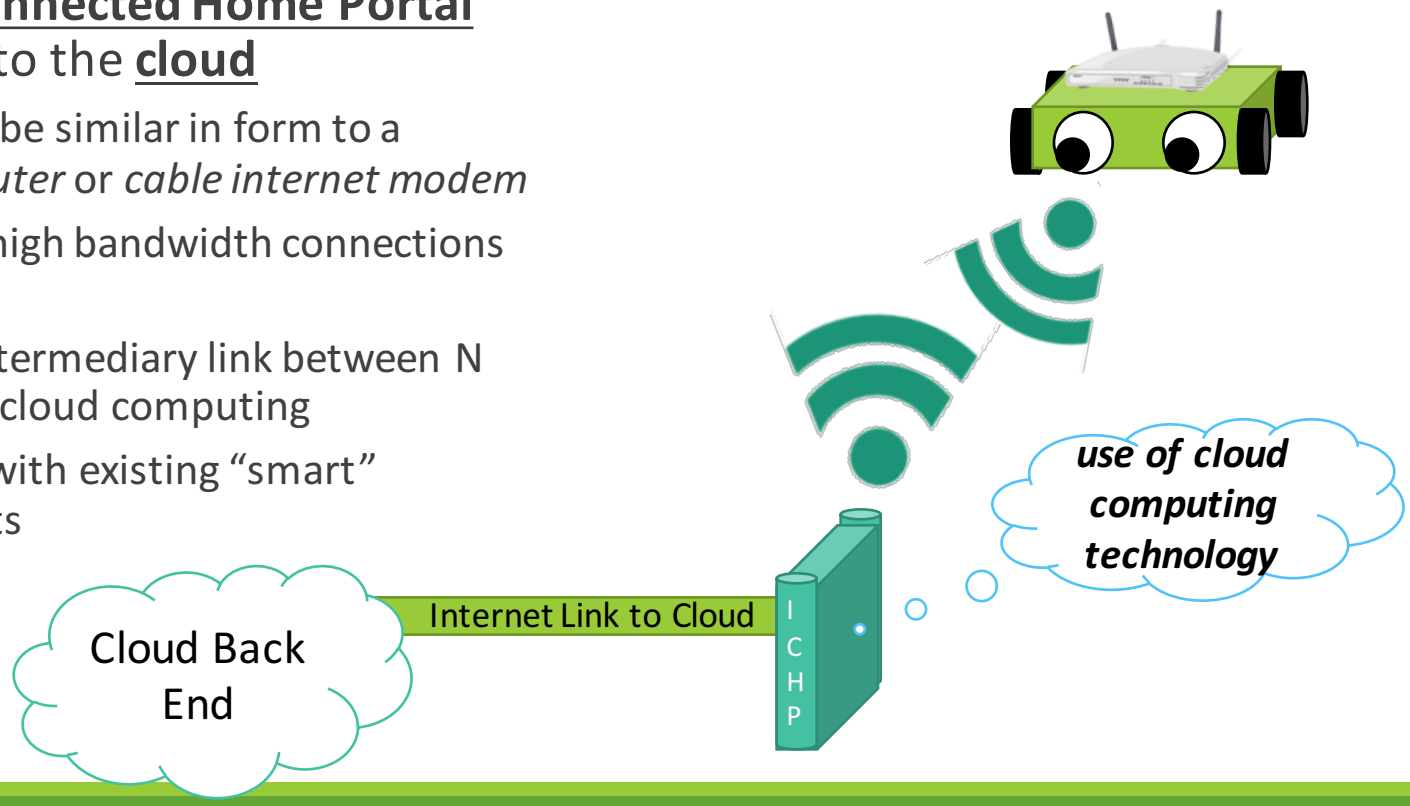

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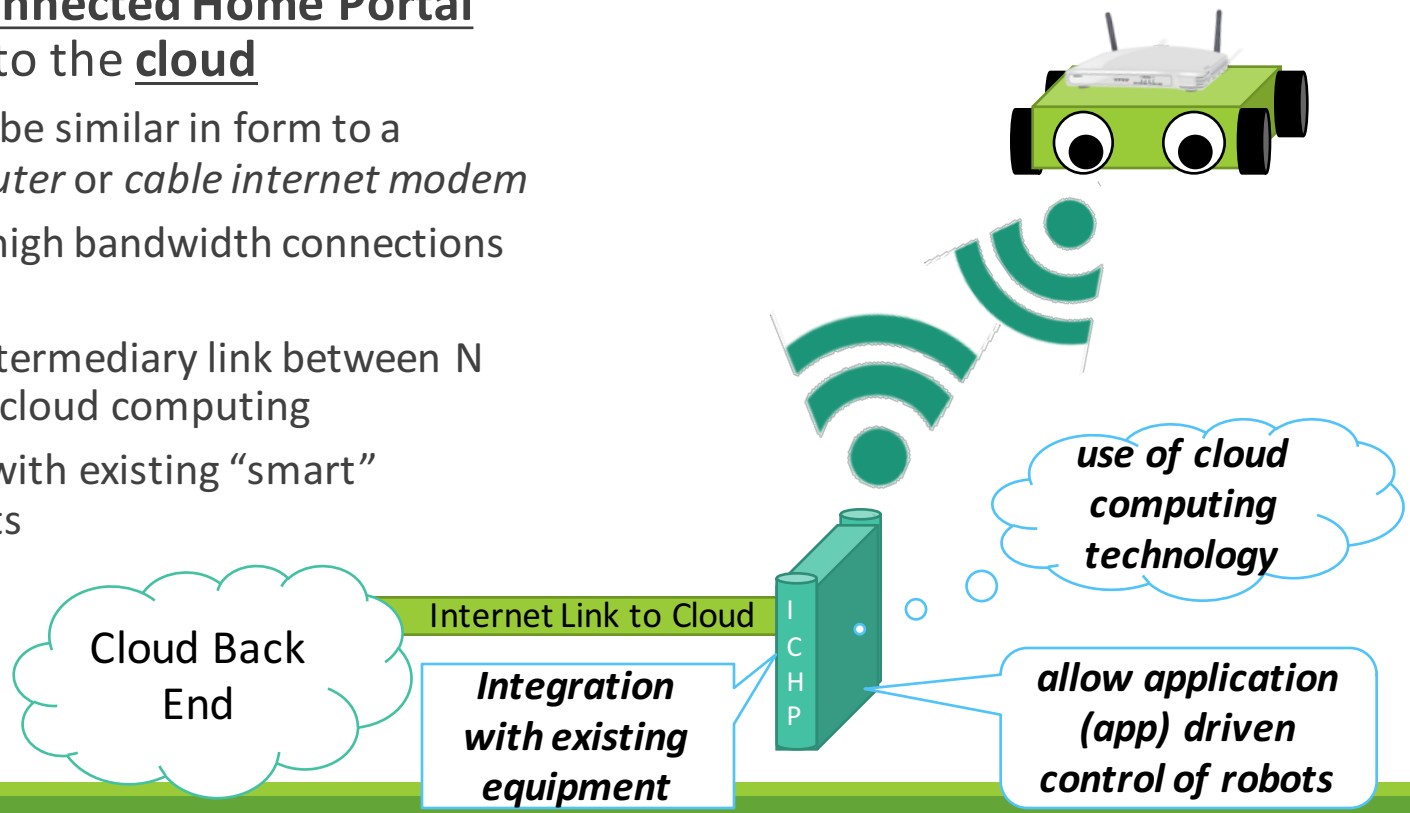

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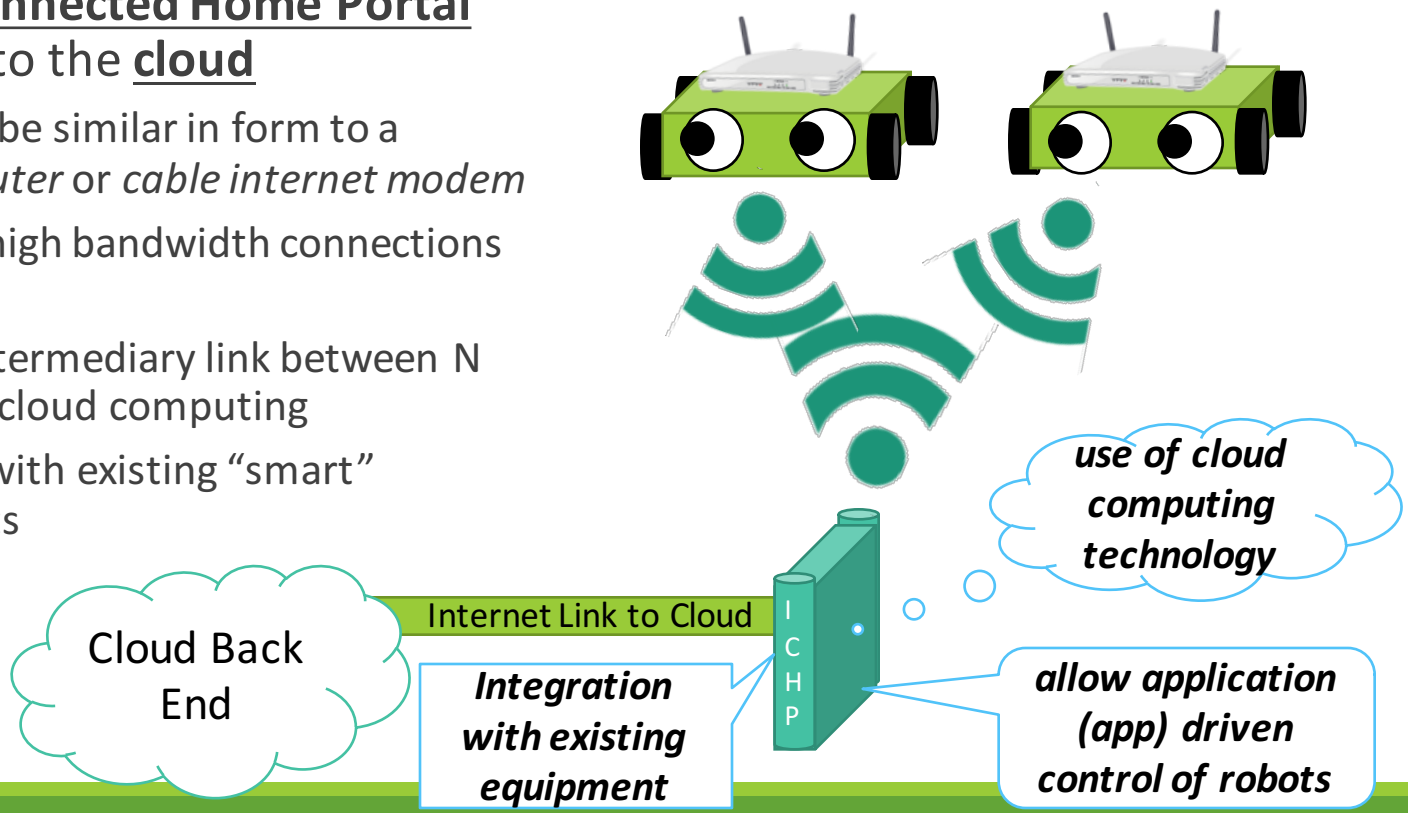

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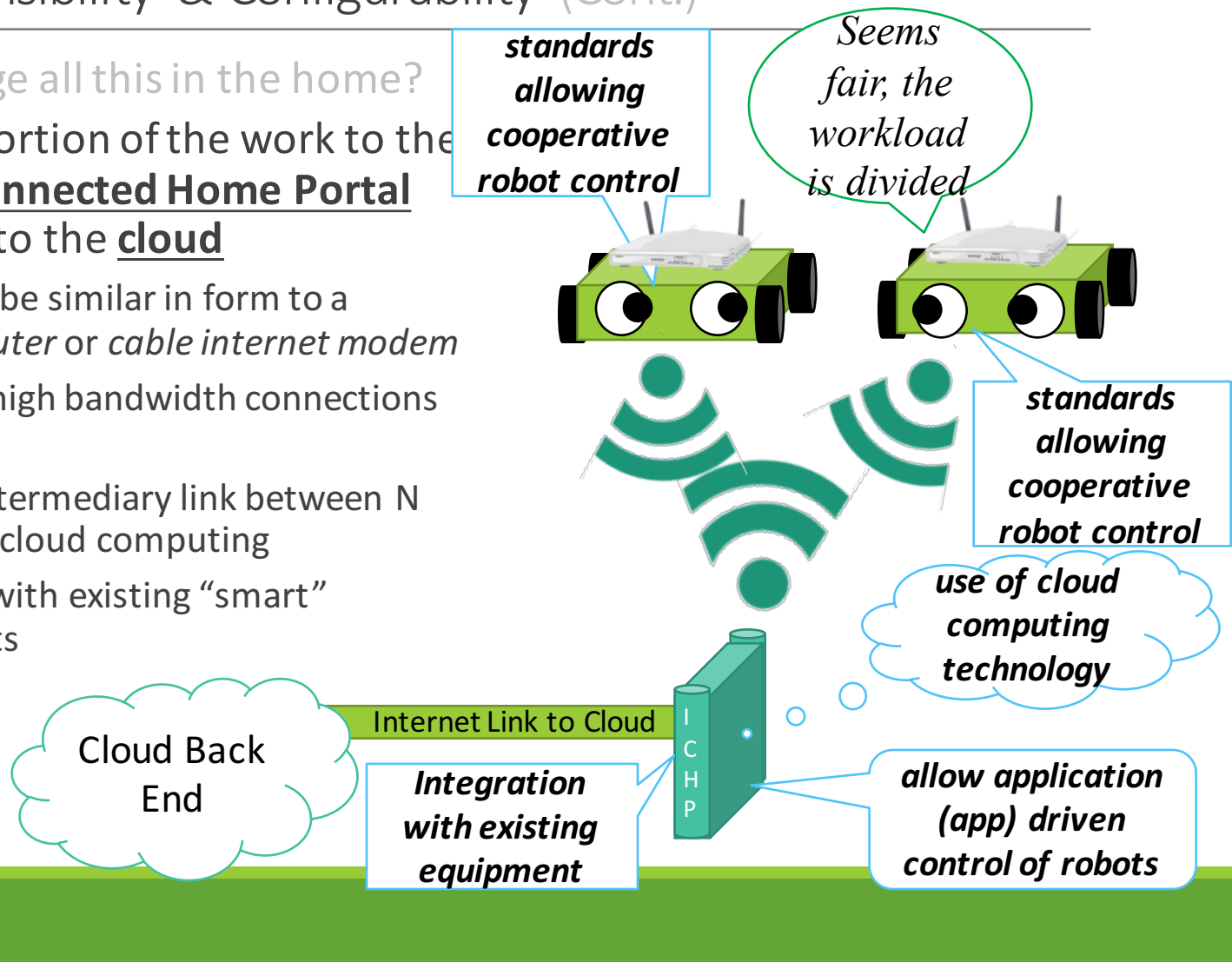


Proposed Home Robot System

Set of Applications to Suit General Needs of User Population

A proof of concept set of applications are proposed to provide assistance in the following areas:

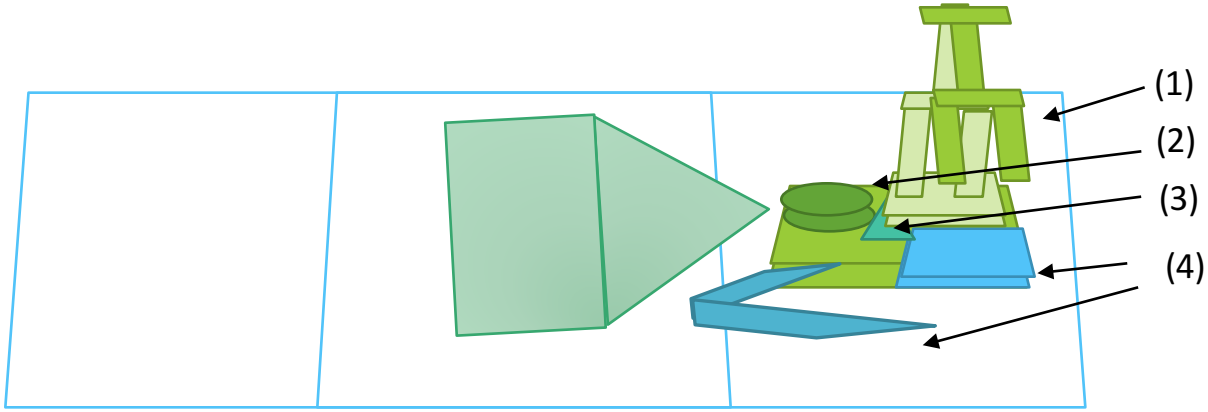
- Vision & Social
- Mobility
- Physical
- Cleaning and Safety

We propose that these tasks be split between two type of robots:

- Movement and Vision Assistance Robot (MVAR)
- Floor Cleaning Robot(FCR)

Proposed Home Robot System

Floor Cleaning Robot (FCR)

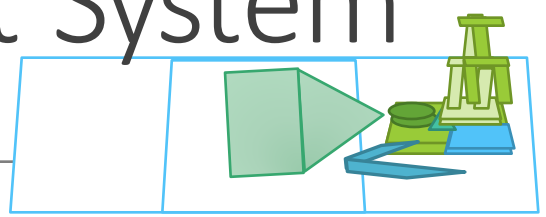


Components

- Manipulator arm (1)
- RGB-D input device (2)
- Vacuum or other cleaning device (3)
- Object retrieval scoop and bay (4)

Proposed Home Robot System

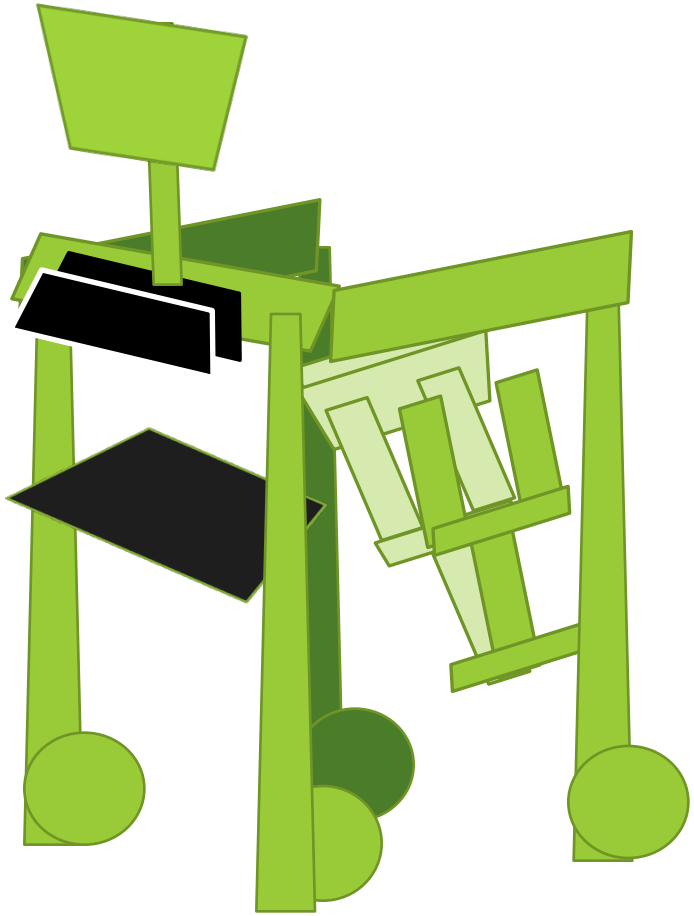
Floor Cleaning Robot (FCR)



Floor Cleaning Tasks	Driving Technology
Dirty area identification for vacuuming/sweeping/mopping	RGB-D based dirty area identification
Small object pickup	Floor RGB-D model comparison and/or database lookup
	Mapping of house walkways
	Manipulator mechanism and control
Self-emptying of dirt bin	Manipulator and dirt bin mechanical compatibility
	Identification of trash can area by RGB-D
Liquid spill identification and cleanup	Spill identification
	Mopping bar tool
	Navigation to spill location

Proposed Home Robot System

Movement and Vision Assistance Robot (MVAR)



MVAR

Components

- Wheeled walker frame
- Tablet screen UI
- RGB-D camera (i.e. Kinect)
- Manipulator arm
- Motors
- Batteries
- Electronics

Proposed Home Robot System

Movement & Vision Assistance Robot (MVAR)

***Movement Assistance* Tasks**	**Driving Technology**
Assist in bearing weight of user	Assistive braking
	Pressure Sensors
Passive path suggestions if obstacles block current path	Obstacle detection via RGB-D sensor and learned floor model
	Grade detection via RGB-D and accelerometer sensors
Active path control to avoid critical obstacles and paths	Same as passive system above
	Velocity control of platform
"Come-to-me" feature	Mapping of house walkways
	Beacon and sensor array
	Teleoperation
Exercise and/or rehabilitation	Pre-programmed exercises
	Waypoint following

Proposed Home Robot System

Movement & Vision Assistance Robot (MVAR)

***Vision Assistance* Tasks**	**Driving Technology**
Reading visual text input	Navigation/manipulation to obtain picture of text input
	Optical character recognition (OCR) on visual input
	Synthesize read text to speech
Reading emails out loud	Save email text to appropriate format for voice synthesis
	Voice synthesis of digitally formatted words
Accept voice commands	Voice recognition software to decode verbal commands
	Turn decoded commands into actions
	Verbal Response
Zoom-in on visual input for display on large tablet screen	Optical zoom
	Digital zoom

Proposed Home Robot System

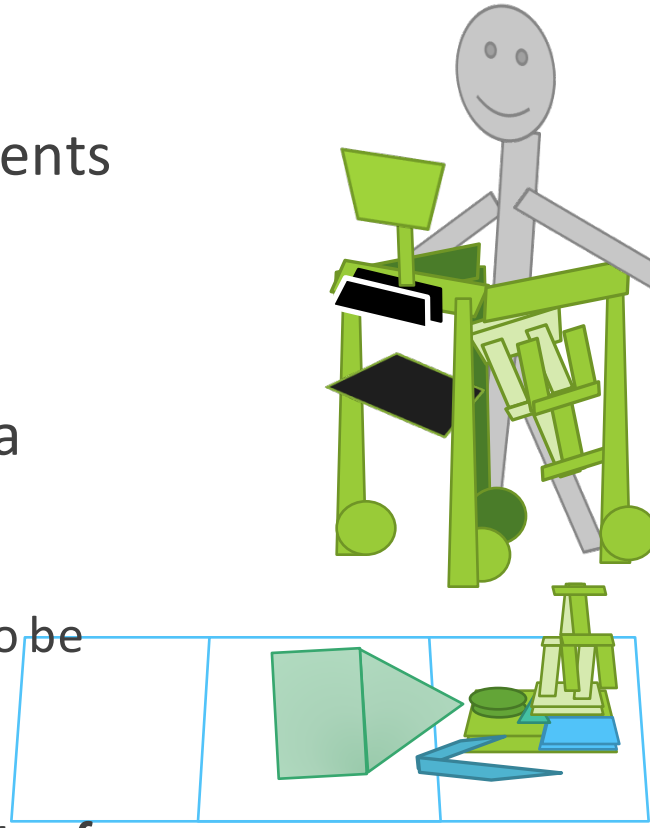
Cooperative Controller

Cooperation is a necessity for household robots operating in overlapping environments with human operators involved

Current household robots like the Roomba move until they hit obstacles.

- Small scale homogeneous (swarm-style) robots colliding with one another is usually assumed to be acceptable **(Roomba Fight Video)**

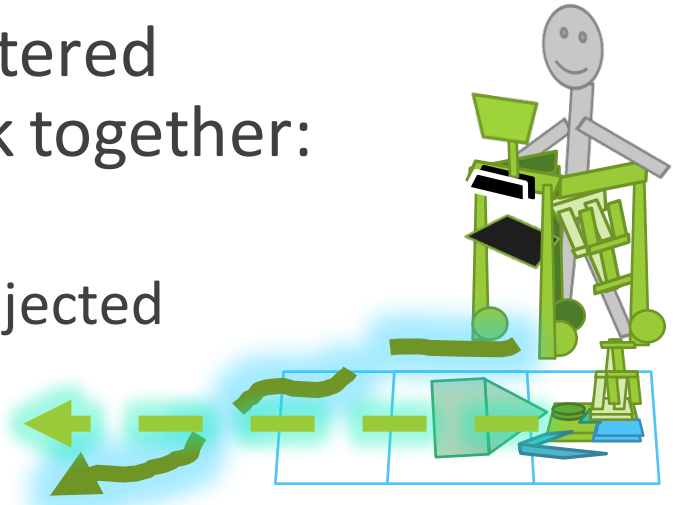
- ***But this is NOT sufficient considering that safety of the user IS THE TOP CONCERN***



Proposed Home Robot System

Cooperative Controller

Example situations will be encountered where MVAR and FCR should work together:

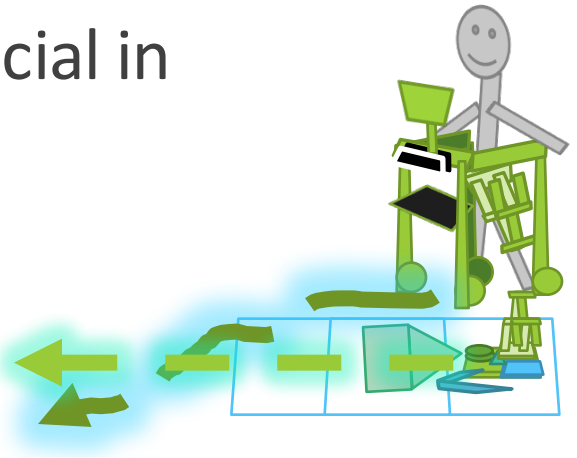


- MVAR crosses paths with FCR in a projected trajectory **(pictured)**
- FCR finds a dirty area under MVAR frame
- Transporting items picked up by FCR to MVAR to user/operator

Proposed Home Robot System

Cooperative Controller

Policies need to be established for situations where cooperation is either beneficial in terms of:



- safety (to prevent operator injury)
- cost reduction (to use smaller cheaper components, i.e. smaller robotic arms) and sharing across both platforms

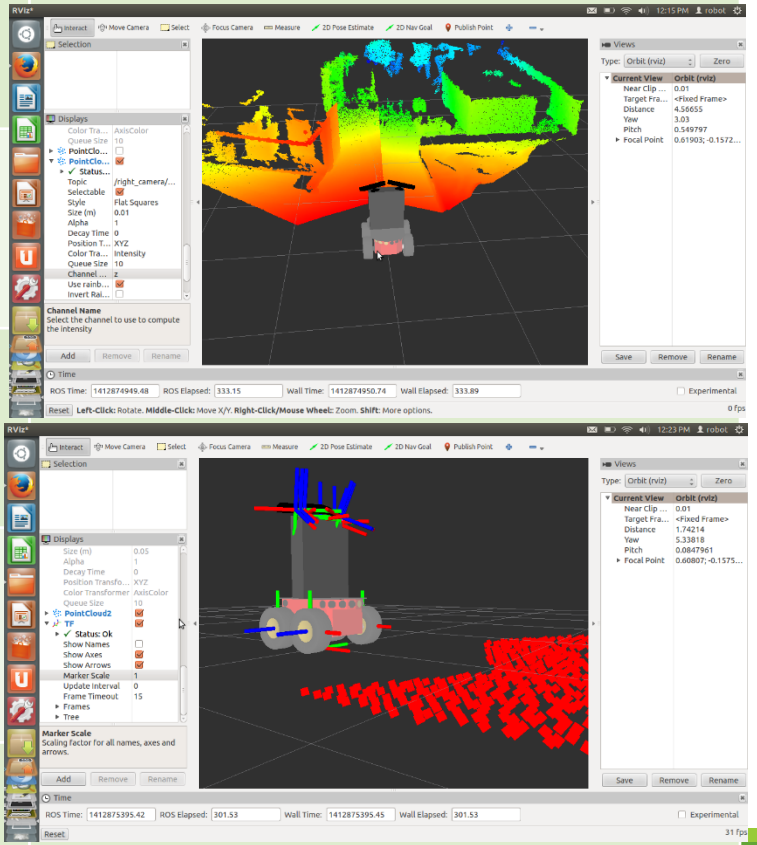
Proposed Home Robot System
Cooperative Controller

Cooperative Controller **Tasks**	**Driving Technology**
Robot-to-Robot coordination of navigation actions	Swarm-based simulation of intended paths for collision detection and flagging
	Task priority driven decision making
	Communication of actions via wireless radio
Human-to-Robot coordination of robot-to-human navigation actions	Human detection and tracking
	Verbal/visual/non-verbal communication of action to human
	Safety driven decision making
Human-to-Robot coordination of coupled Robot-to-Robot actions	Communication to begin action
	Navigation to close proximity
	Identification of manipulation action

Software and Simulation Environment

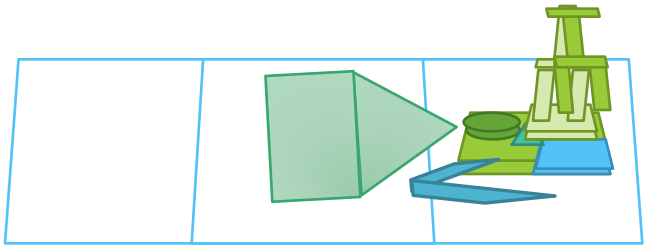
Software and Simulation Environment

Software	Name and Version
Operating System	Ubuntu Linux 12.04 LTS
Robot Middleware	Robot Operating System (ROS) (Hydro Release)
Image Processing	OpenCV 2.4.6 (ROS Hydro Release Version)
3D Point Cloud Processing	PCL 1.7.0 (ROS Hydro Release Version)
3D Simulator	ROS Gazebo Simulator 1.5?

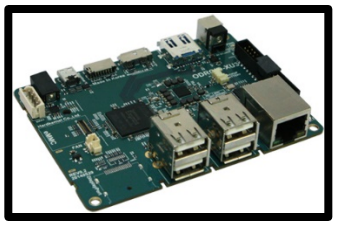


Hardware

Hardware – FCR



More rigid 3D printed prototype

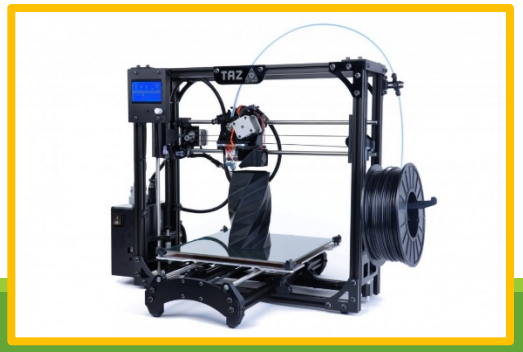


http://dn.odroid.com/homebackup/XU3LiteMain.jpg

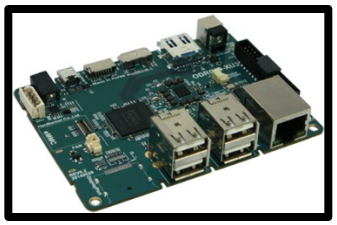
http://en.wikipedia.org/wiki/Kinect

Roomba Discovery (circa 2004)

Very early prototype



Hardware – MVAR



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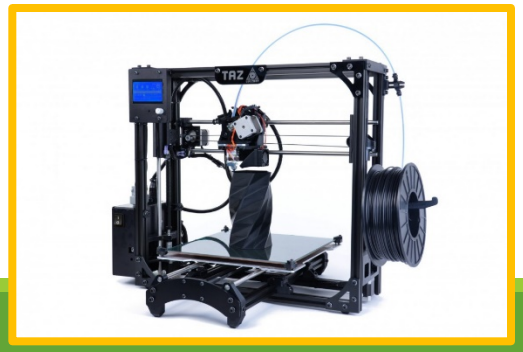
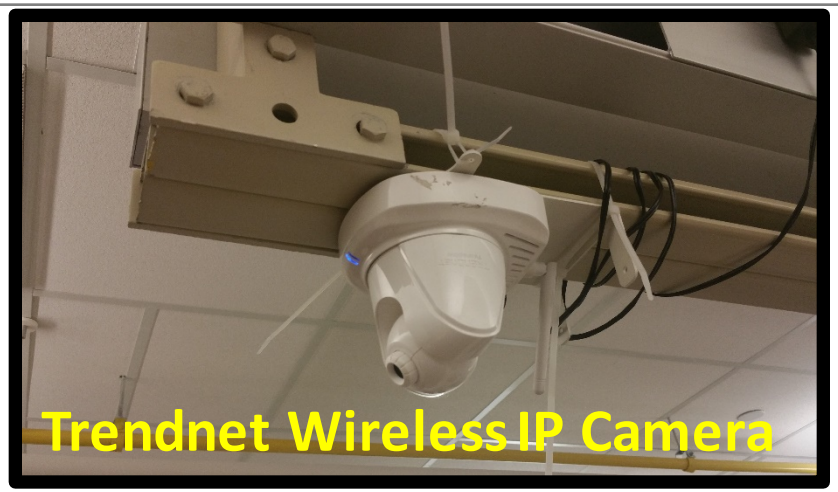
Design to be completed soon



Nova GetGo Walker
SolidWorks model by UTSA's Eric Wineman

Hardware - Infrastructure



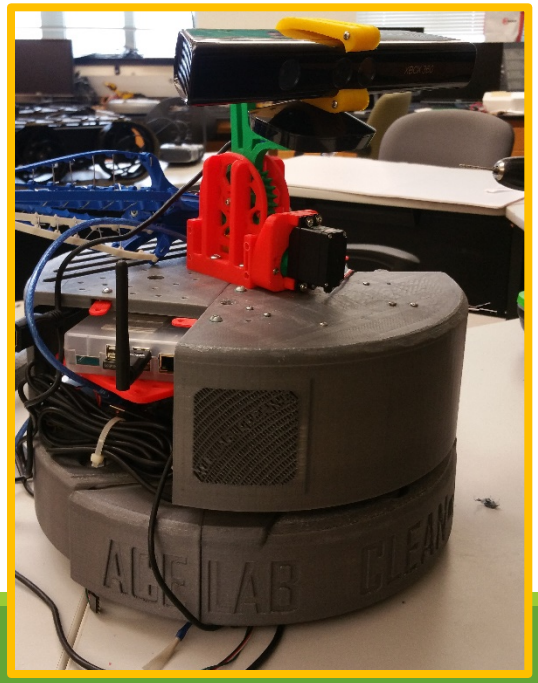
http://www.linksys.com/images/productmt/834023/372.jpg

Summary of Contributions and Completed Work

Completed Work

Modifications to drive a salvaged iRobot Roomba in ROS

- Wired motor drivers and Arduino microcontroller to computer
- Added lithium polymer battery for extended use
- Added Kinect and related hardware
- Added an embedded ODROID Xu3 computer with 8 cores in big.LITTLE configuration
- 3D Printed and assembled under-actuated gripper
- 3D Printed many components of robot base ~200 printing hours



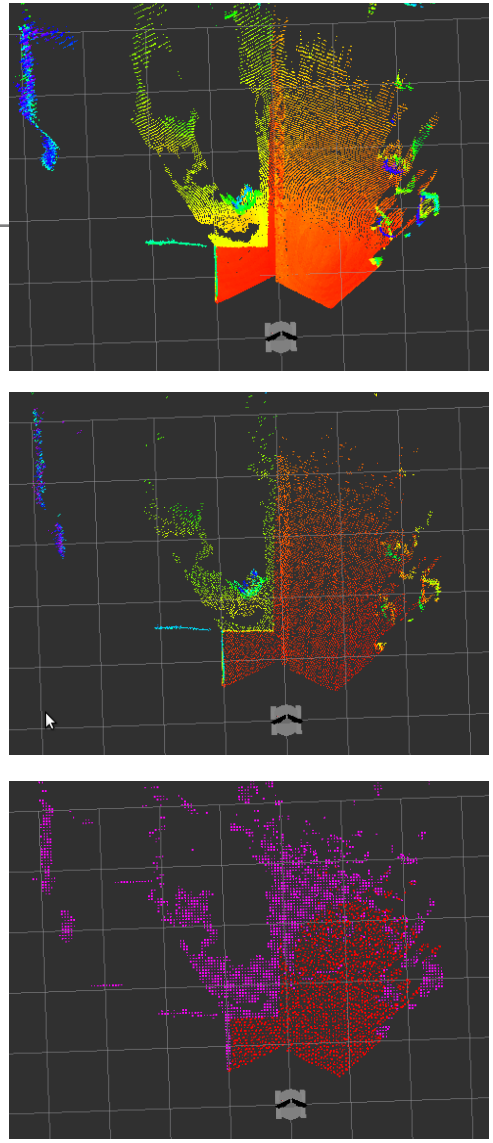
Completed Work

3D point cloud data processing

- Now very experienced in PCL software
- Methods to filter, geometrically transform to fix orientation, and process data

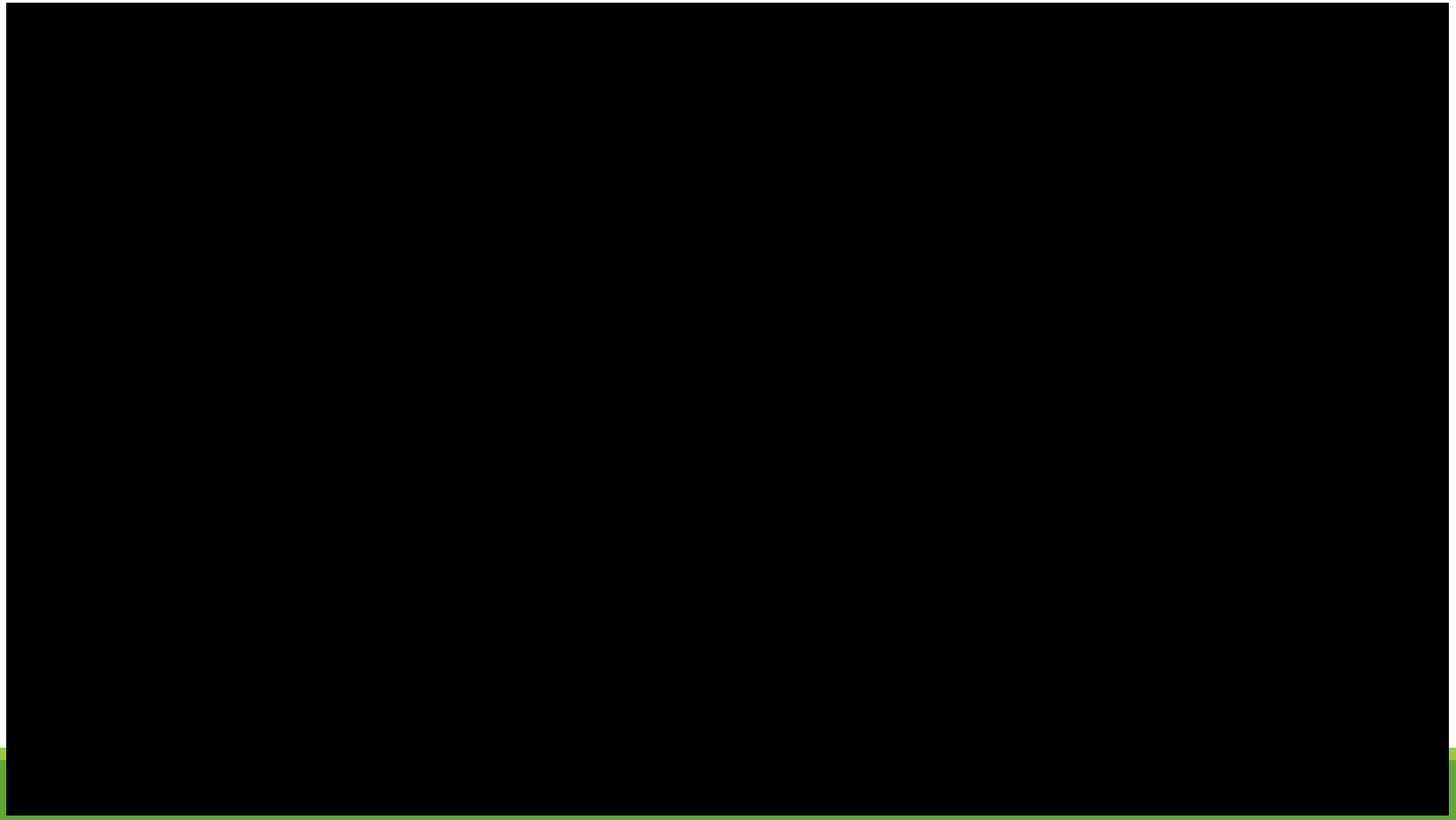
RGB+D image processing

- Calibrated cameras of the Kinect
- Software developed to acquire and process both RGB & D images in ROS for processing



Completed Work

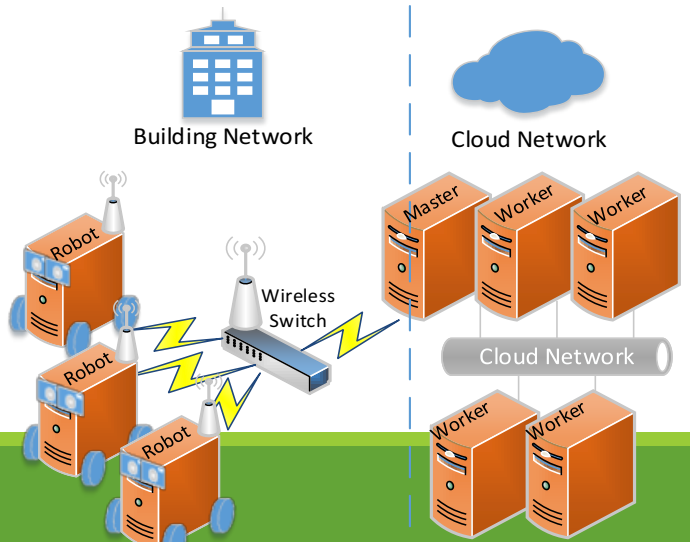
Commercial cleaning motions & control examples

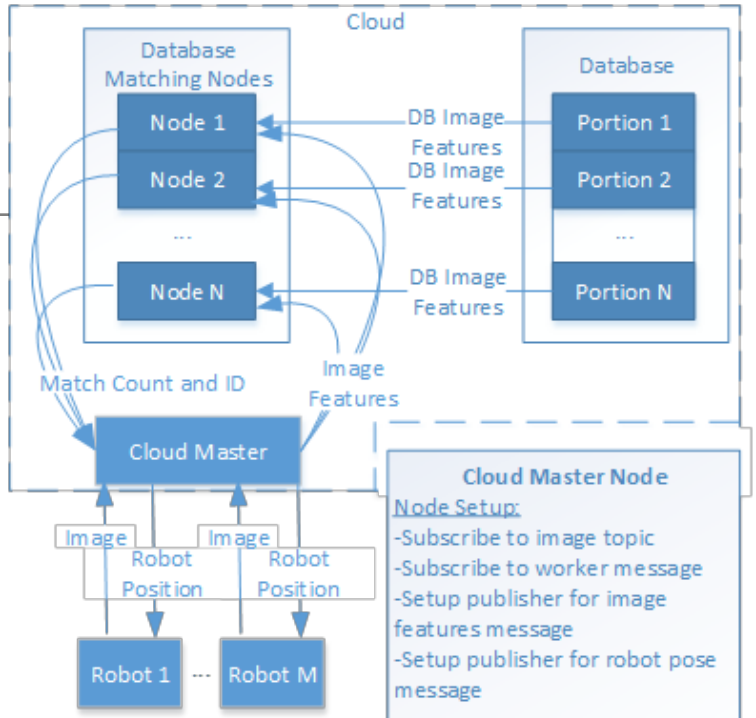


Completed Work

ROS on the Cloud

- Feature matching for Visual SLAM via ROS-based mechanism similar to MPI
- Implemented the network setup for successful experimentation





Database Matching Node

Node Setup:
-Subscribe to **Image Features** topic
-Setup publisher for **Match Count and ID**

On RX of **Image Features** Message:
-For each image features in DB portion:
--Count matches between RX and DB image features
-Publish top match count and database ID data on **Match Count and ID** topic

Cloud Master Node

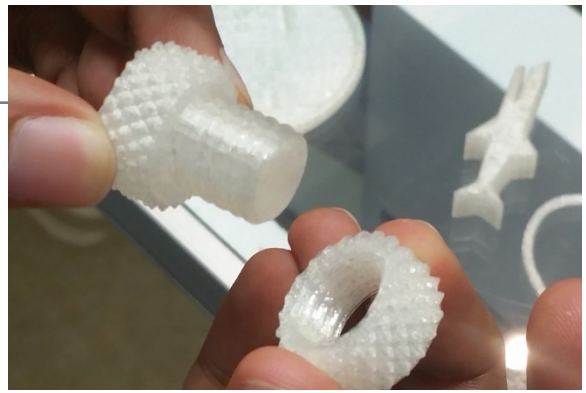
Node Setup:
-Subscribe to image topic
-Subscribe to worker message
-Setup publisher for image features message
-Setup publisher for robot pose message

On RX of **Image** Message:
-Process image for image features
-Publish **Image Features** message

On RX of **Match Count and ID** message:
-Accumulate into array of **Match Count and ID** messages
-If all **Match Count and ID** messages have been received:
--Rank IDs by match count to select database winner
--Get coordinates for winner from database
--Publish **Robot Position** topic

Future Work

Future Work



FCR

Add manipulator arm*

Simulation on FCR Small Item Detection

Experiment on FCR Cleanup of Small Liquid Spill

MVAR

Add manipulator arm*

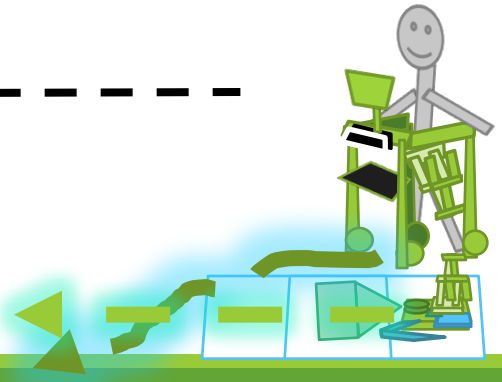
Simulation on Home State Recognition

Experiment on Passive and Active Navigation

Cooperative Controller

Simulation on Robots Crossing Paths

Experiment on Small Object Handoff



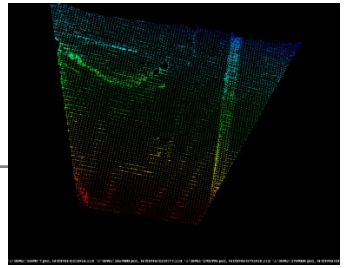
*Custom designs using 3D printed parts from ACE Lab's soon-to-be acquired 3D printer

Simulations

Home State Recognition

- Goals:
  - 1) Detect states of light switches in a room.
  - 2) Detect state of deadbolt locks.
- Limitation: Use of datasets taken in apartment and in ACE Lab of light switches
- Time permitting: the simulation will become an experiment with live detection of the switch state

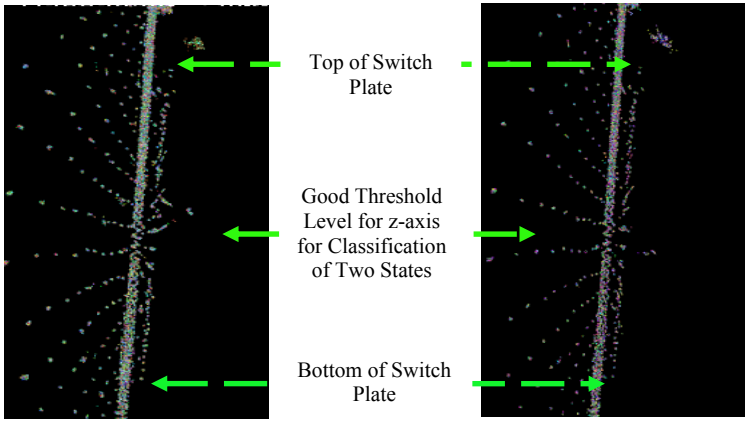
RGB Image of Scene



Voxel Grid Filtered 3D Point Cloud of Scene

Zoom-in on Switch in Up State

Zoom-in on Switch in Down State



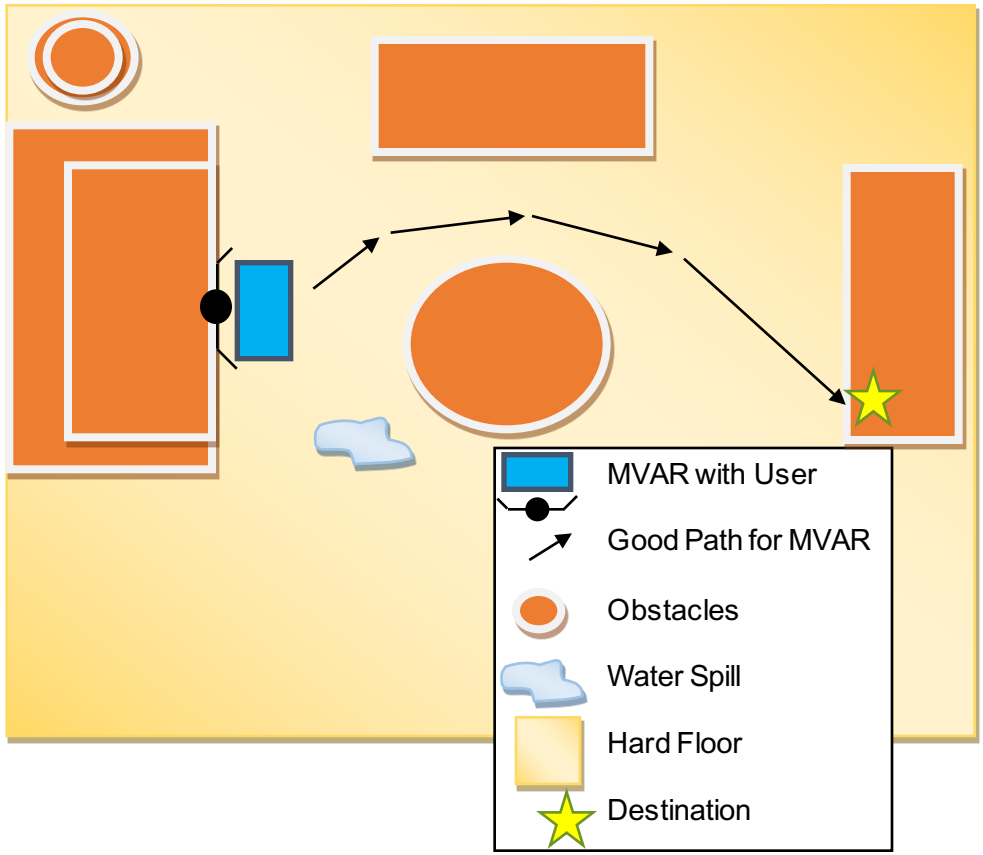
Zoom-in on Side Profile of Switch in Up State

Zoom-in on Side Profile of Switch in Down State

Experiments

MVAR Passive and Active Navigation

- Goal: Navigate through an environment typical to that of a household.
- Limitation: dataset only from apartment, experiment in ACE Lab



Questions?

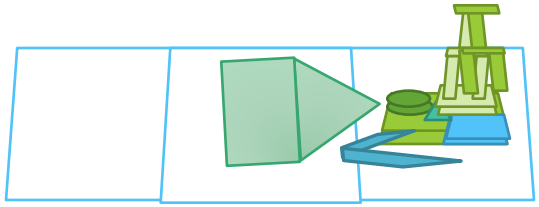
Contributions

This work contributes following five items to the field of home robotics:

- A new concept for a home multi-robot system for elderly care
- Methods and system for a Floor Cleaning Robot (FCR)
- Expansion of multi-robot system thinking to home robots with robot/human and robot/robot interactivity
- Methods and system for a Movement and Vision Assistance Robot (MVAR)
- A cooperative controller for enabling and organizing multi-robot interaction.

Proposed Home Robot System

Floor Cleaning Robot (FCR)



External Controller

Robot Actions

External Observer

Other Robot

Desired Actions & Reactions

Robot's Actions

Environment

Actuation

External Actors

High Level Controllers
(Clean Area Avoidance, Small Object Manipulation, Cooperative Controller)

Low Level Controllers
(Obstacle Avoidance, Motion planning)

Controllers

Sensor Data

Onboard Sensors (Distance, Velocity, Position, Force)

Robot

External Computer

Environmental

Proposed Home Robot System

Movement & Vision Assistance Robot (MVAR)