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

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Abstract - *Home-based assistive robotic care for the elderly and disabled has long been a goal of robotics researchers. Unfortunately, no single group has solved the problem of making robots that will perform a set of tasks sufficient enough to warrant the cost to the end consumer. Numerous advances and improvements in computing, communication and related robotic technologies have been paving the way towards cheaper, more capable robots. We propose a home robot system consisting of a set of heterogeneous robots with different task spaces, cloud computing to enhance the abilities of the system, integration with existing home infrastructure, and compatibility with mobile technology. A high level of integration with the open source software of the Robot Operating System (ROS) is proposed to accelerate the design process. For the exact types of robots, we propose to use an enhanced floor cleaning robot and a mobility and vision assistance robot in the form of an improved rollator walker.*

Keywords: indoor robot, vSLAM, ROS, assistive robotics, cloud robotics, service robot

1 Introduction

The IEEE Robotics and Automation Society notes that Europe, Japan, Korea and maybe to a lesser extent, the United States are all interested in rehabilitative robotics [1]. Many examples of robots have been developed for rehabilitative and assistive purposes in the forms of "smart" wheelchairs [2-5], humanoid assistant robots [6-10], telepresence robots, serial manipulators [11-16], floor cleaning robots, and rollator walkers.

Robocup, the international group known for their soccer robot competitions created the "@Home" event specifically geared towards developing functionality of service and assistance robots. In each competition, the rules are set in such a way that they push forwards the level of completeness that assistive robots have in their functionality. Robots are stress tested in these competitions under sets of unique inputs from environments that participating teams have no control in structuring. Commonly seen in the robots in the competition are the capabilities of voice recognition, navigation, and visual pattern recognition. Component-wise, the robots include serial manipulator arms, a wheeled base, and an approachable human-like face. These capabilities and components are required based on the rules and the challenges presented to the participating teams by RoboCup planning staff.

Mobility assistance robots provide many services to users, such as anti-collision sensors, navigation, and/or voice control [3-5]. Smart wheelchairs overall have appeared numerous times in the literature and cover a wide variety of concerns [4]. Few "Smart rollators" have been developed by different groups and focus on improving key parts of the design. Focuses include collecting data [17], determining intent of the user and assisting for navigation purposes [18, 19], braking for stability purposes [20], and estimations of leg pose at the viewpoint of the rollator [21]. Each of these different designs have similarities in that all concern primarily on how the user is doing while operating the machine. Not rollators with manipulator arms have been observed in the literature.

Floor cleaning robots are becoming more commonplace in consumer homes. Each year new manufacturers release robots with incremental improvements made to the vacuuming process, scheduling features, navigation and cosmetic design. Few manufacturers tackle some realistic reasons as to why these robots are not commonplace in households. Only recently have vacuuming robots received the secondary task of mopping floors while vacuuming. Without more than one feature, robots will not be deemed useful to end users. With the current set of floor cleaning robots, there is a certain level of maintenance that may not be possible for elderly and disabled persons to complete on their own.

In this paper we present an assistive home robotic system comprised of multiple robots supported by a cloud computing backend and internet connected home management portal. The purpose of this system is to reuse as much existing infrastructure as possible while adding a considerable benefit to the end user population, the elderly or disabled.

The structure of this paper is as follows: Section II provides the proposed home robotic system, Section III provides some of the proposed simulations and experiments for the system, and Section IV provides conclusions and a look forward towards the future work.

978-1-4799-7611-9/15/$31.00 ©2015 IEEE

2 Proposed Home Robotic System

Technological components of the proposed home assistive system include a set of heterogeneous home robots, an internet connected home management portal, a remote cloud server, environmental cameras, and personal mobile devices. Each of these components are depicted in Figure 1. Important to the system, each component can be utilized independently, enhance the capabilities of the entire system, and do not have to be present together for each system to work. The robots for instance can be controlled via a personal mobile device directly or through the home management portal. The home management portal enhances the system performance by adding an additional computer in the network for offloading compute power. It also acts as an intermediate node between the cloud and robots. On the cloud, data can be processed at a much finer detail than can be done onboard the robot computers and the home management portal. When more robots are added into the system, the efficiency of the system will increase to a certain point before the system is saturated in terms of home traffic, network and computing capacity.

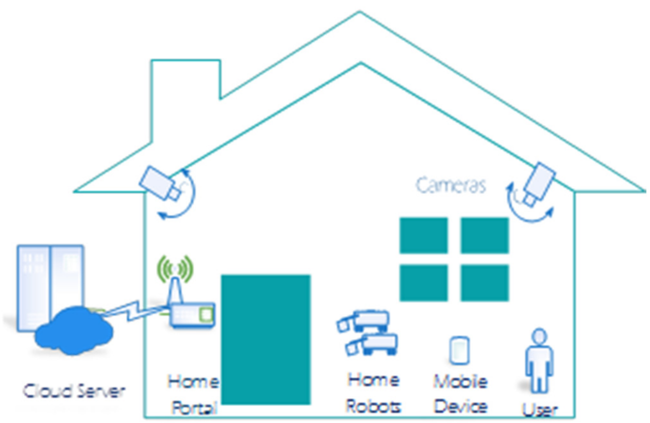

Figure 1: Proposed Home Robotic System

2.1 Network Control and Cloud Computing

Network based controllers for robots are ideal when the computational power of the computer on a robot is limited and upgrading to a higher powered system would not be beneficial or is infeasible. Instead of processing data and control calculations solely on the robot's computer, a network controller receives sensor data from the robot, processes it and sends the robot a control input. These actions make the computer on the robot act in a "thin-client" configuration where it acts mainly as an intermediate communication node between controllers and sensors.

An important aspect of working in a cloud environment, is that the computational power of a cloud server can be scaled up to satisfy processor and memory intensive applications without any noticeable service interruptions. Examples of complex operations that can be moved to cloud servers for processing include Simultaneous Localization and Mapping (SLAM), feature-rich image processing algorithms, and the kinematics and path planning for robot manipulators.

Network based control applications can be deployed to the cloud infrastructure provided that communication requirements (such as uplink speed, downlink speed and latency) support such a deployment. Network requirements exist in the home environment between robot and wireless hub, between the internet via the wireless hub link and cloud network and back. Uplink connections to the internet are typically limited by internet service providers to be much lower than the downlink speed.

Typical residential uplink speeds for broadband in the US have been limited to 1 or 2 Mbps, while gigabit WiFi routers have become common in the home. Consider a cloud-based VSLAM algorithm as an example. Without considering image compression or communication overhead, streaming raw images from a typical webcam (640x480 pixels) to the cloud at 30 frames per second, would utilize just over 220 Mbps (ImageSize x BitDepth x Frame Rate). Without a considerable increase in uplink bandwidth via gigabit internet services (i.e. Google Fiber, AT&T), real-time cloud based data processing will not be possible on uncompressed images. Image size reduction, framerate reduction, compression, and local feature processing would be obvious choices for limiting the required uplink bandwidth per robot. The overall computing network is depicted in Figure 2.

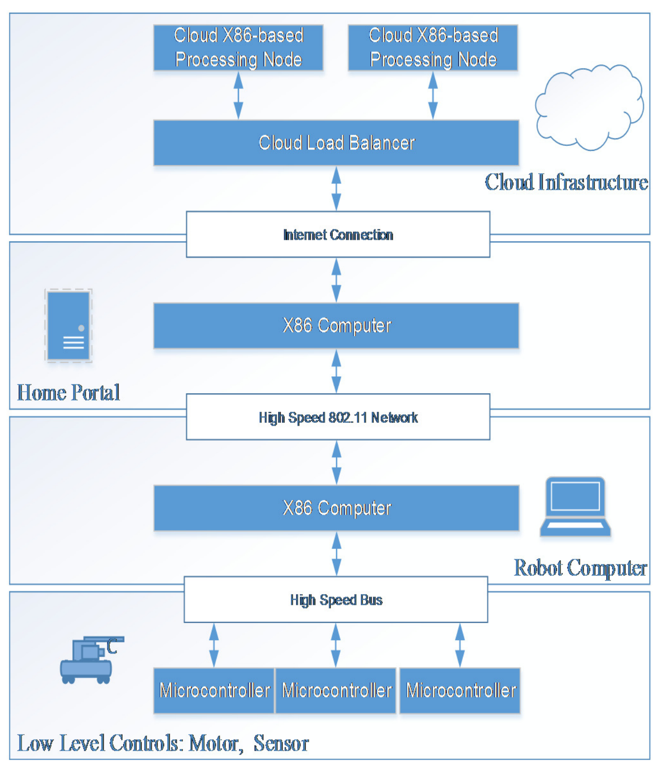

Figure 2: Proposed Computing Network

2.2 Home Management Portal

A home portal, or computer interface, to the robot system is to be deployed in the home. The purpose of the home portal is to collect, aggregate, process and transmit data from the various robots and sensors operating in the home to allow for user-friendly control of the system. Information is queried from the robots using standard IP based networking protocols such as one of the WiFi 802.11 variants. As a user interfacing tool, users will be able to access system states and parameters from the home portal via mobile devices or touchscreen interface. As a data processing node, the home portal would perform in one of two modes depending on the computing capability of the hardware that the portal uses: 1) full or "good-enough" local processing of the data without the cloud processing nodes OR 2) limited local processing and forwarding of data to remote cloud processing nodes for full feature-rich data processing.

2.3 Integration of System with Existing Home Infrastructure

Many homeowners have installed security systems with input coming from cameras, infrared, temperature, contact, and other types of sensors. An even larger number of homeowners have access to high speed internet available over their personal IEEE 802.11 wireless networks. Reuse of existing infrastructure, when possible, is warranted for the home robot system in order to reduce its overall cost and to reduce duplication of services to the end-user. Existing home computing and networking infrastructure can be useful only if it meets minimum hardware specifications of the overall system. For example, higher wireless bandwidth, low-latency wireless routers may be necessary for installations relying more on network control.

Robots add value to security systems as they can act as active or passive security scouts during lulls in activities required by the users. Many consumer installed security cameras provide for password protected, open-to-computer access to a Motion-JPEG (or similar) image stream that can be used for locating robots in a room or for determining the state of the house. Integrated security systems, however, may have more protections on access to sensor data via only proprietary applications. Current home security systems will likely trigger a robot as being an intruder based on motion or infrared sensing. Therefore, support from third party security system companies would be required to successfully deploy the home robot system in a commercially installed security system.

2.4 Robot Operating System

Researchers often spend large amounts of time to write their own code for basic programs interfacing with sensors, controllers, computer networks, and other programs. Many times researchers only aim to test algorithms and not their full understanding on how to program low-level controls. The Robot Operating System (ROS) [22] was created by Willow Garage to enable rapid development of robotic systems by supplying various levels of robot functionality to users across the world for free as open source code. Code developed with ROS can run on many operating systems including many free Linux operating systems, with Ubuntu and Android being two examples.

ROS provides two main features to users: 1) a core set of Advanced Programming Interfaces (API) functions and computer services to facilitate message passing between programs and computer networks, and 2) a managed wiki-like forum to host a set of user submitted drivers that are compatible with the base services. In ROS, drivers and APIs were already made publically available by others for the Microsoft Xbox Kinect [11], Motion JPEG (MJPEG) video streaming [12], image processing with Open Computer Vision (OpenCV) library, and processing 3D point clouds with the Point Cloud Library (PCL).

ROS contains software bundled into packages and stacks. Packages are collections of code for developing one or more executables or processes. Stacks are collections of related packages. In our experiments we use several different stacks and packages to assist in development of robot capabilities in terms of sensing, human interaction, and low-level robot controls. Table 1 lists software packages used in the experiments that are available in the Robot Operating System.

Table 1: Software packages in ROS used for experimentation

Task	Software	Additional Information
Speech recognition	pocketsphinx ros kinect	ROS Pocketsphinx Tutorial [23], Pi Robot Tutorial [24]
Processing depth images	ROS Opencv2	OpenCV API [25, 26]
Processing depth point clouds	pcl-ros	PCL API [27]
Optical character recognition	Open Source OCR Engine Tesseract	Tesseract API [28]
Voice Synthesizer	eSpeak	eSpeak API [29]
Scientific Computing in Python	Scipy Stack: numpy, scipy, matplotlib, pandas	SciPy API [30]

2.5 App-based Functionality

Use of mobile-device based applications (or "apps") can greatly expand the usefulness of a system. Take for example a rehabilitation task with a manipulator arm and a user. The user is to follow a pre-defined set of motions of a manipulator arm to enhance the health or workings of their own personal arm. Following the trajectories of the manipulator arm repeatedly can be disheartening or even boring if the motions become too repetitive. Even with a change in the pattern or some coaching along the way, the exercise becomes new again. App based updates to the functionality must be performed to keep the system new and refreshed. A lack of interest on behalf of the system developers would likely cause a similar response on the consumer end.

3 Hardware

3.1 Robots and Sensors

Two types of robots are in development which can provide great benefit to disabled individuals. A Floor Cleaning Robot (FCR) is proposed to provide services related to floor cleaning and safety. A Movement and Vision Assistance Robot (MVAR) provides mobility, vision, and safety services to the user. Both robots will utilize the Microsoft Kinect as their primary sensor, enabling color and 3D recognition of objects and scenes. Motors, encoders, and sensors are interfaced with an Arduino microcontroller running a low level ROS serial interface. An ODROID-XU3 embedded computer running ROS collects data from a Microsoft Kinect and the Arduino. It then communicates the data over an IEEE 802.11n WiFi connection with other computers in the ROS network.

A modified iRobot Roomba robot forms the base platform of the prototype FCR. Modifications have been made to control the wheel motors, encoders and brush motors via an Arduino. An off the shelf walker rollator, a Nova GetGo Rolling Walker, forms the robot base of the MVAR system. An off-the-shelf model was selected not only as a low-cost alternative to developing a new walker frame, but a potential selling point. Aftermarket modifications to change a walker rollator into a robot can be done on multiple manufacturer's products, which can inevitably reach a wider user base. Early prototypes of the MVAR and FCR are depicted in Figure 3.

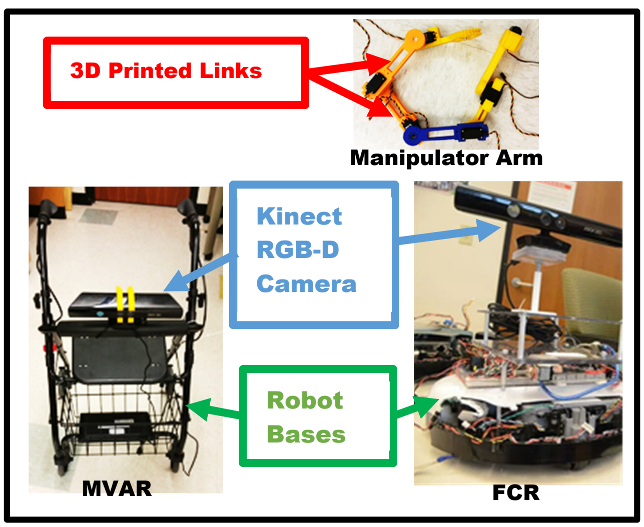

Figure 3: Robot Prototypes under Development

3.2 Cloud Computing Hardware

To process the Kinect RGB+D and/or derived point cloud data, we propose the use of the Research Data Center, a cloud computing system on the campus of The University of Texas at San Antonio (UTSA). Robot experiments and simulations will be run with the following infrastructure equipment depicted in Figure 4 providing a backend computing system.

Figure 4: Infrastructure Hardware in System

Also in Figure 4 is a wireless internet protocol (IP) camera. IP cameras form the part of the existing infrastructure reuse portion of any experiments requiring fine tracking of a particular robot or set of robots.

4 Simulations

A variety of simulations will need to be performed to develop the capabilities of the assistive robots. Examined in this section are two examples of the robot capabilities under simulation, home state detection and navigation.

4.1 Home State Detection

Of the many ways to evaluate the system, we aim at its usefulness of the system in common everyday situations. A person's memory for example can often be clouded as to the state of a light switch or a door lock. Given a camera sensor like the Microsoft Kinect with vision input capable enough of determining the state of the lock or a light switch, the states can be recorded as a robot passes through a household environment. Figure 5 shows a scene with a light switch as the target for investigation using RGB and 3D depth data as input.

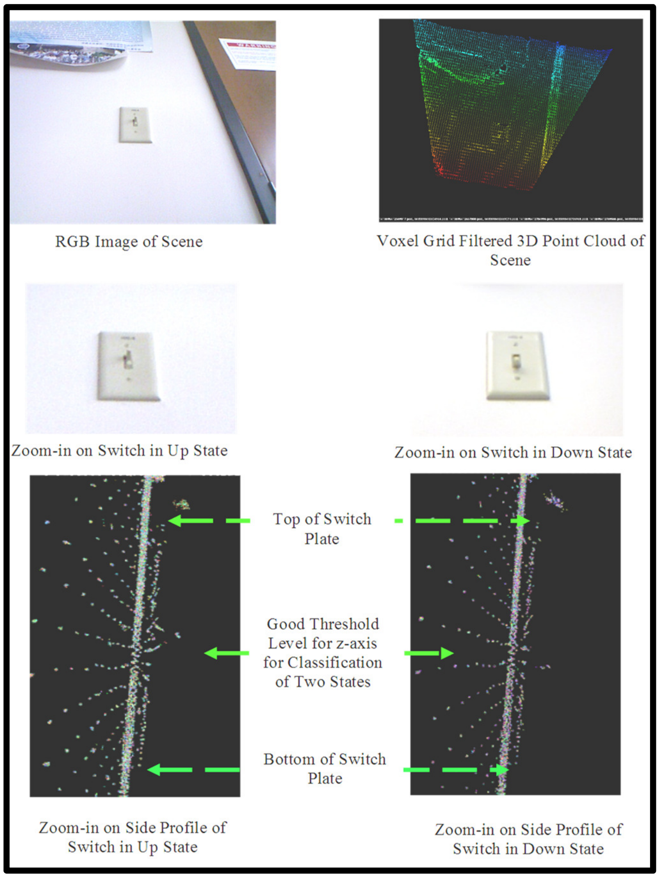

Figure 5: Light Switch State Recognition 3D Data Study

The state of the switch is mostly recognizable with the RGB image, while the 3D depth data is essential in positively confirming the state of the switch.

4.2 Navigation

The proposed assistive robot system provides the following services to the user: a "come-to-me" automated user pick up, touch-based map navigation, security patrols, passive navigation and active navigation. Results of the author's previous studies in VSLAM [31] are displayed below in Figure 6.

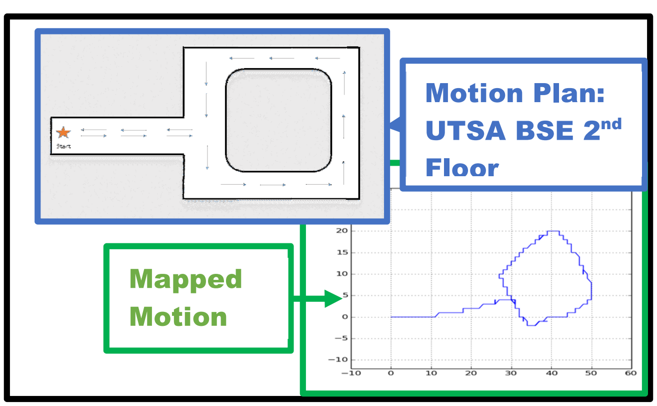

Figure 6: Simultaneous Localization and Mapping Results

5 Conclusions

In this paper we provided the basic design principles of our proposed home multi-robot system. We proposed use of infrastructure equipment that the authors have utilized successfully in other research ventures such as cloud-based SLAM and other cloud-based image processing applications. In the near future, both the FCR and MVAR platform designs will be completed. Experiments and simulations of their main tasks will be performed. Standards for judging efficacy of the actions taken by the robots in their tasks will be inspired by the Robocup @Home results both in the literature and those posted in video format online.

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