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# Towards ROS based Multi-Robot Architecture for Ambient Assisted Living

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***Abstract*—The demographic trend is towards ageing in our society and the number of people with physical impairments and disabilities will increase dramatically in the future. It is necessary to deliver advanced healthcare and services to these people so that they can live independently and stay well at home throughout their lifespan. This paper presents a multi-robot architecture for ambient assisted living of the elderly and disabled, which is based on the robot operating system (ROS). A communication bridge is proposed for different means of human robot interaction, and ROS provides a framework for rapid system development with a reduced cost. Some experimental results are given in the paper to demonstrate the feasibility and performance of the proposed system.**

***Index Terms*—Ambient assisted living, ROS, Intelligent wheelchair, Navigation, Ageing society, Well-being.**

## I. Introduction

Population ageing is widespread across the world according to the United Nations population statistic reports [1]. The demographic change towards ageing is an urgent and daunting problem in our society, as well as a dramatic growth in the number of population with physical and cognitive impairments. As a results, the demand and cost of care for the elderly and disabled people is raising rapidly in many countries, which puts heavy pressures to the families and governments and lead to dramatic challenge to current healthcare system [2]. Information and Communication Technologies(ICT) can make significant contribution to deal with these problems.

The term of ambient assisted living(AAL) emerged in 1990s processes ICT-based solutions to provide services and systems for ageing well at home or in the community, at work, thus, improving their quality of life and reduce the pressure of caregiver. AAL systems are now drawing plenty of attention from the community of ICT. The EU has launched an Action Plan for Ageing Well to investigate and develop the innovation technology on AAL. Recent years, a vast number of research projects in the field of AAL have been launched worldwide, such as iDorm [3] propose a smart environment with fuzzy logic based agents, and a service robot framework for AAL named RoboCare [4]. [5] introduced a framework for supporting context-aware in a smart environment. The EU Ambient Assisted Living Joint Programme [1] was founded to provide a collaborative platform for AAL research.

[1]http://www.aal-europe.eu/

Typically, an AAL system involves sensing, reasoning, acting, interaction and communication. Heterogeneous components are integrated to a AAL system to provide services such as mobility, living assistance, healthcare etc. Though there have been a number of ICT-based products developed, it is still a great challenge to coordinate and integrate distributed components to produce a human-centred AAL system. There is no common definition of ambient assisted living and their potential applications are vast. For instance, as the essential service in a AAL environment, an intelligent wheelchair is one kind of mobility services to the elderly or disabled people with mobility impairment.

The research on intelligent wheelchair commenced in 1980s, and a series of long term projects have been carried out since, such as Wheelesley [6], NavChair [7], VAHM [8], and [9]. However, most of these wheelchairs only functioned well in laboratories and few of them are available on the market so far. On the other hand, service robots have been widely deployed in AAL systems. They can communicate with the other components in a AAL system to exchange information [10] [11]. Note that the current ALL systems are still too expensive to build and operate. It becomes a priority to develop new AAL strategies and framework by using open source software and the hardware that are already available.

ROS (Robot Operating System) [12] is a free-available robot development framework that provides state-of-the-art robot control technologies from the robotics research community. It contains many software modules and stacks that are ready for building a robot control system, including basic control models and autonomous navigation functions. ROS allows developers to share knowledge and reduce the development time. It is a successful "eco-system" for robotic research and development, and reduce the cost of complex robot system development. ROS now has been being accepted and employed by many projects such as Mason [13], Borja [14], Arumugam [15], Schulman [16], Lane [17]. In this paper, a multi-robot system architecture based on ROS for AAL is presented.

The rest of the paper is organized as follows. Section II describes the background knowledge and the statement of problems for the system. Section III presents the system architecture based on ROS for the AAL system. Some experimental results are given in Section IV to demonstrate the feasibility and performance of the proposed multi-robot

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architecture and the AAL system. Finally, a brief conclusion and future extension are presented in Section V.

## II. Background

### A. Ambient Assisted Living and Service Robot

Ambient intelligence(AmI) refer to ICT-enabled intelligent, embedded(invisible or non-invasive), digital environment that is sensitive and responsive to the presence of people. It provides personalized, adaptive and anticipatory services to people in needs [18]. It involves multi-disciplinary knowledge such as ubiquitous computing, human-machine interface, robotics, intelligent systems, etc. AAL utilizes AmI technology but put emphasize on the independent living. In AAL systems, the hardware components can be divided into two groups: embedded devices that are static and and service robots that are moving. Embedded devices is supported by WSN(Wireless Sensor Network) technology, ubiquitous(anything and anywhere) computing, context-awareness, data management, computer vision, behaviour modelling etc. Service robots aspect mainly involve human-robot interaction, robot control and navigation. This paper focuses on the service robot aspect.

### B. ROS and Software Development

ROS provides a framework for large-scale development of complex robot systems. It consists of a number of processes connected in a peer-to-peer topology network. Each process is a node which interacts with other nodes by XML-RPC based message via topics/services, as shown in Fig. 1. ROS contains a large number of algorithms and tools which is reusable for robot system development, which are based on various open source projects among the communities. For example, mobile robot navigation modular, SLAM, planning algorithm module, motion controller is from PR2, Stage/Player [12], and rescue robots. The vision modular is from OpenCV and OpenNI, and the voice module is supported by Sphinxs. The Nao project contributes to the humanoid motion planning and navigation module. The modular functions can be directly deployed into other robots, as well as integrated with user software by some configuration. In ROS, a *launch* file, i.e. XML like script, is used to bring up the modular functions together and to configure parameters of each node, from which a functional robotic system can be developed.

## III. System Design

### A. Smart Environment with Multiple Service Robots

Fig. 2 shows a AAL system that is to be developed for the EU COALAS project. This smart home environment consists of two parts, static sensors and mobile robots. The furniture are attached with RFID tags, temperature sensors, cameras, IMUs, etc. These sensors are communicateing each other via a wireless sensor network (WSN) based on ZigBee technology. A service robot SCITOS, a humanoid NAO robot and a powered robotic wheelchair are deployed to provide assistance to people in needs. The HMI(Human-Machine Interface) devices are developed for easy access of the AAL.

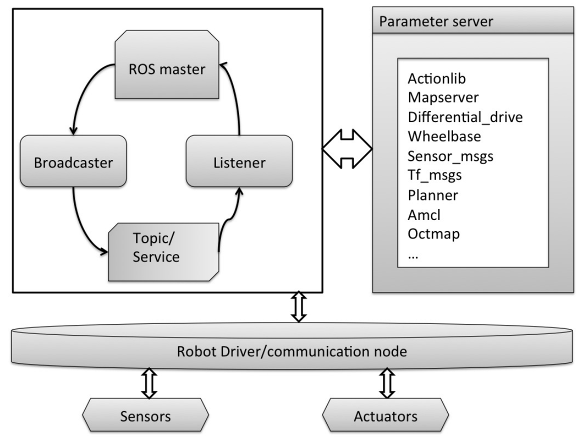


Fig. 1: Communication Nodes in ROS

The proposed system is capable of autonomous navigation, multiple modality of human-machine interaction, and multi-robot collaboration. Robots share the information from users, including position and service command. For instance, when a user sits on the wheelchair and need some drink, the service robot receives the message from the wheelchair and gets the current position. With RFID tags, the service robot can find where the drink is and fetch it to the user. Another scenario is, when the wheelchair has difficult to pass a narrow door or hallway, the service robot can play as a guide role in front and help the wheelchair by share position and commands. With such features, the system is capable of facilitating the elderly with cognition and physical impairment for daily task. It also can provide assistance to the caregivers to minimise their effort. For example, a caregiver can remotely control the robot to help the elderly or disabled, and monitor their heath context, as well as the other scenario of assistance.

The infrastructure of the robots control system is based on ROS. As shown in Fig. 3, the navigation and motion control utilise the modular provided by ROS. The information and knowledge of service robots are exchanged each other via topics/services. The message is defined as ontology based knowledge representation in the XML format which is compatible to the core message format in ROS. The message exchange is coordinated by a master node. Each robot and master are connected with wireless Ad-hoc networks.

To integrate the HMI devices for human-robot interaction, we designed a bridge node in ROS to subscribe messages from the HMI devices and to deliver commands to service robots for actions. The bridge node allows users to trigger the actuators for autonomous navigation and to accomplish their missions. It also enables the service robot to adapt to different user profiles and preferences. For example, a caregiver can send a text message by an application from their phone to the wheelchair to initialize the medicine taking task. The HMI bridge is a client/server program that wraps the message data type and structure. Within the bridge, we also employ


Fig. 2: Design of a multi-robot based AAL system

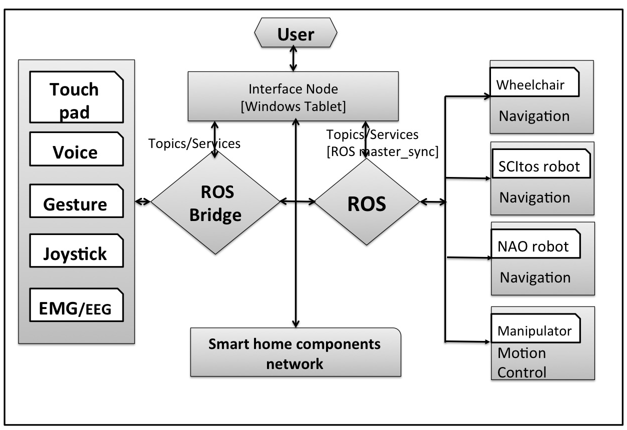


Fig. 3: ROS based collaborative robot system

semantic representation of environment and human activities which allows robots understanding natural human commands. For instance, a ontology based semantic map contains the objects (table, kitchen, living room etc.)in the environment. With knowledge processing and reasoning, the user can simply tell the service robot where he/she wans to go by natural language.

### *B. Electric Powered Wheelchair Hardware*

A commercial powered wheelchair is equipped with embedded computers and sensors in this research, including Sonar sensors, Hokuyo laser scanner, Mongoose IMU, Optical encoders and a Linux embedded PC for low-level motion control. A laptop PC is used for high level control as shown in Figure 4. The embedded PC is connected to the sensors and motors with serial ports. A server program running at the embedded PC can output sensor data and receive commands

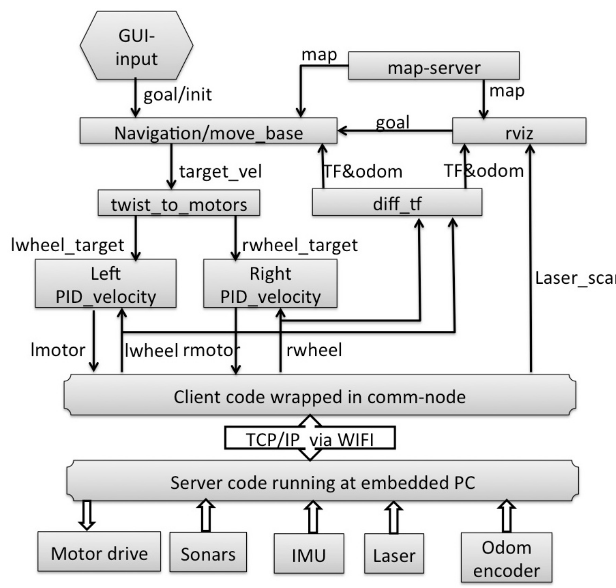


Fig. 4: Navigation system for a Electric Powered Wheelchair

from the laptop PC. On the high level control, a ROS based system is developed and provides autonomous navigation and interaction interface. With the HMI bridge, users can actuate the navigation by the interface according to their preference.

### *C. Navigation Setup for Wheelchair*

As we know, ROS stacks have already provided navigation and control functions modules for Nao robot and SCITOS robot. Here we describe the navigation system we have developed for the wheelchair.

*1) Communication:* As it is mentioned above, ROS topics/services provide task request and responses among nodes via messages. The server program and client program enable the communication between an external PC and an embedded PC. Unified data type and data structure of sensor information and actuator commands are defined in server program. On the high level control platform, the client acts as a message bridge and is wrapped into the ROS navigation package as a *comm* node. Thus, the modules in ROS can take the message from sensors and then process it to generate relevant actions for navigation.

*2) Wheelchair Model and Transformation:* ROS provides various of functional utilities for the robot development. URDF is based on XML language to produce robot models that can be displayed in the simulator *Gazabo* and the robot visualization GUI *Rviz*. A differential driving vehicle model is created by URDF corresponding to the wheelchair. The *tf* package allows users to specify multiple coordinate frames over time. *tf* maintains the relationship between coordinate transform points between any different coordinate frames. The *tf* configuration is set within a *launch* file, including wheelchair base_link, laser and sonar. *tf* messages are subscribed and broadcast between the nodes overtime.

*3) Motion Control with differential_drive:* The *differential_drive* package provides motion control which is independent to motor hard driver. It takes twist messages from navigation stack and broadcasts the twist messages as the strength of motor driver. Contemporaneously, it receives odometry message from the *comm* node and publishes messages to the navigation stack. Within the *differential_drive* package, a PID controller is implemented for wheels velocity control. The parameters of PID, $K_p, K_i, K_d$ is set in a launch file similar as follows.

```
<launch>
 ...
  <node pkg="differential_drive"
   type="pid_velocity.py"
    name="rpid_velocity">
      <remap from="wheel" to="rwheel"/>
      <remap from="motor_cmd"
       to="rmotor_cmd"/>
      <remap from="wheel_vtarget"
       to="rwheel_vtarget"/>
      <remap from="wheel_vel"
       to="rwheel_vel"/>
      <rosparam param="Kp">90</rosparam>
      <rosparam param="Ki">44</rosparam>
      <rosparam param="Kd">0</rosparam>
  ...
   </node>
</launch>
```

*4) Navigation Stack Configuration:* ROS contains a sequence of packages that process the information taken from sensors, and generate proper motion commands for the service robot to research a goal pose. *SLAM_gmapping* provides laser-based SLAM (Simultaneous Localization and Mapping) and can take in sensor data from the world to build a 2D or 3D occupancy grid map of the environment. *map_server* is able to translate map data as ROS service and generate map file with sensor data. *amcl* provides the adaptive Monte Carlo localization approach to track the robot in a known world map. *nav_core* provides global planner and local planner names *base_global_planner* and *base_local_planner*. *base_global_planner* uses *navfn* that wraps the Dijkstra's algorithm to compute a navigation path on a grid map. Trajectory Rollout and Dynamic Window approaches are implemented as *base_local_planner* in ROS. It produces trajectory and motion commands as messages passing to a robot for path following within a given map.

In order to accomplish the navigation task, it is necessary to integrate mapping, localization, planning together. ROS *move_base* plays such a role to link them together. It also maintains two cost maps, one for the global planner and one for the local planner. Since the navigation modular in ROS is lack of doorway passing capability for the wheelchair, a Bézier Curve Trajectory approach is implemented [19] for doorway passing. Finally, to activate all the navigation components, a launch file is generated to specify the parameters, dependences, functions of nodes, and the packages for the navigation task. A simple GUI allows users to choose a goal position for the robot.

## IV. Experiments and Analysis

In this section, the experiments and analysis of the ROS based wheelchair autonomous navigation are conducted in a real indoor environment, i.e. our robot arena and robotics research offices.

### A. Motion Control Test

In order to improve the accuracy of the wheelchair motion controller, we firstly tested the wheelchair by sending specific twist topic to the differential_drive which corresponds to the relevant motion command to the two motors. Then we configured the parameters of PID in *launch* file until the wheelchair move correctly with regard to the twist message. In this experiment, the parameters, $K_p$, $K_d$ and $K_i$ of the PID controller are set to be 90, 40 and 0 respectively.

### B. Mapping and Localization Test

Laser and odometry data is recorded during the robot explores the environment, as shown in Fig. 5. Fig. 6 is the grid map of a clutter environment generated with laser scanning data. In order to generate a good map, it is necessary to carry out the exploration a number of times in a close loop manner. The laser data and odometry is stored in rosbag which can be replay after exploration. The following two commands is used to process sensor data and produce a binary map image file. *map_server* and *slam_gmapping*. Run the following commands, it can produce a binary grey image map file.

- *$rosrun gmapping slam_gmapping scan:=base_scan _odom_frame:=odom*
- *$ rosrun map_server map_saver*

### C. Autonomous Navigation Test

Once the environment map and the robot position are generated, we test autonomous navigation capability of our ROS based system. After a goal position is selected from the map, the navigation schema on the robot is actuated to drive the robot toward the given goal. In Fig. 7, the red arrow shows the origin position. The yellow trail is the visualization of the

Fig. 5: Test environments for the wheelchair

wheelchair trajectory in Rviz. The status of visualization model and real wheelchair are contemporary with regard to the map and the environment.

## V. Conclusion

This paper proposes an ROS based multi-robot architecture for a AAL system. Users can interact with the robots and smart home via the HMI(Human-Machine Interface) devices. The system enables service robots to achieve autonomous navigation, multiple modalities operation, human-machine interaction, and multi-robot collaboration. Robots share information such as their own positions and the commands from the user. An intelligent wheelchair was deployed to implement the autonomous navigation task in which it can reach a goal position selected by users from the environment map.

In future work, the adaptive planner and the doorway passing navigator will be integrated into our ROS-based system. Also, RFID will be delpoyed for indoor navigation and high-level path planner with a semantic map will be implemented. Some HMI systems that have been developed at Essex, such as voice dialogue system, gesture controller, EMG based motion controller and EEG based emotion controller, will also be deployed in our system for better quality and robustbness.

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## References

[1] United Nations, "World population ageing: 1950-2050." [Online]. Available: http://www.un.org/esa/population/publications/worldageing19502050/

[2] EU-IST Advisory Group, "Ambient Intelligence: from vision to reality," Tech. Rep., 2003. [Online]. Available: ftp://ftp.cordis.europa.eu/pub/ist/docs/istag-ist2003_consolidated_report.pdf

[3] F. Doctor, H. Hagras, and V. Callaghan, "A Fuzzy Embedded Agent-Based Approach for Realizing Ambient Intelligence in Intelligent Inhabited Environments," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 35, no. 1, pp. 55–65, Jan. 2005.

[4] A. Cesta, G. Cortellessa, M. V. Giuliani, L. Iocchi, G. R. Leone, D. Nardi, F. Pecora, R. Rasconi, M. Scopelliti, L. Tiberio, A. Cesta, G. Cortellessa, M. V. Giuliani, R. Rasconi, M. Scopelliti, and L. Tiberio, "The RoboCare Assistive Home Robot : Environment , Features and Evaluation The RoboCare Technical Reports," National Research Council of Italy, Tech. Rep., 2006.

[5] A. Fides-Valero, M. Freddi, F. Furfari, and M. Tazari, "The PERSONA framework for supporting context-awareness in open distributed systems," in *Ambient Intelligence*, 2008, pp. 91–108.

[6] H. Yanco, "Wheelesley: A robotic wheelchair system: Indoor navigation and user interface," *Assistive technology and artificial intelligence*, 1998.

[7] R. Simpson, S. Levine, and D. Bell, "NavChair: an assistive wheelchair navigation system with automatic adaptation," in *Assistive Technology and AI*, 1998, pp. 235–255.

[8] G. Bourhis and P. Pino, "Mobile robotics and mobility assistance for people with motor impairments: rational justification for the VAHM Project." *IEEE transactions on rehabilitation engineering*, vol. 4, no. 1, pp. 7–12, Mar. 1996.

[9] J. C. Augusto, "Smart Homes as a Vehicle for AAL," in *Handbook of Ambient Assisted Living*, ser. Ambient Intelligence and Smart Environments, J. C. Augusto, M. Huch, A. Kameas, J. Maitland, P. J. McCullagh, J. Roberts, A. Sixsmith, and R. Wichert, Eds. IOS Press, 2012, vol. 11, pp. 387–388.

[10] H. Nakashima, H. Aghajan, and J. Augusto, *Handbook of ambient intelligence and smart environments*. IOS, 2010.

[11] I. G. M. F. Alonso and J. M. Maestre, *Service Robotics within the Digital Home:Applications and Future Prospects*. Springer, 2011.

Fig. 6: An environment map built by laser data

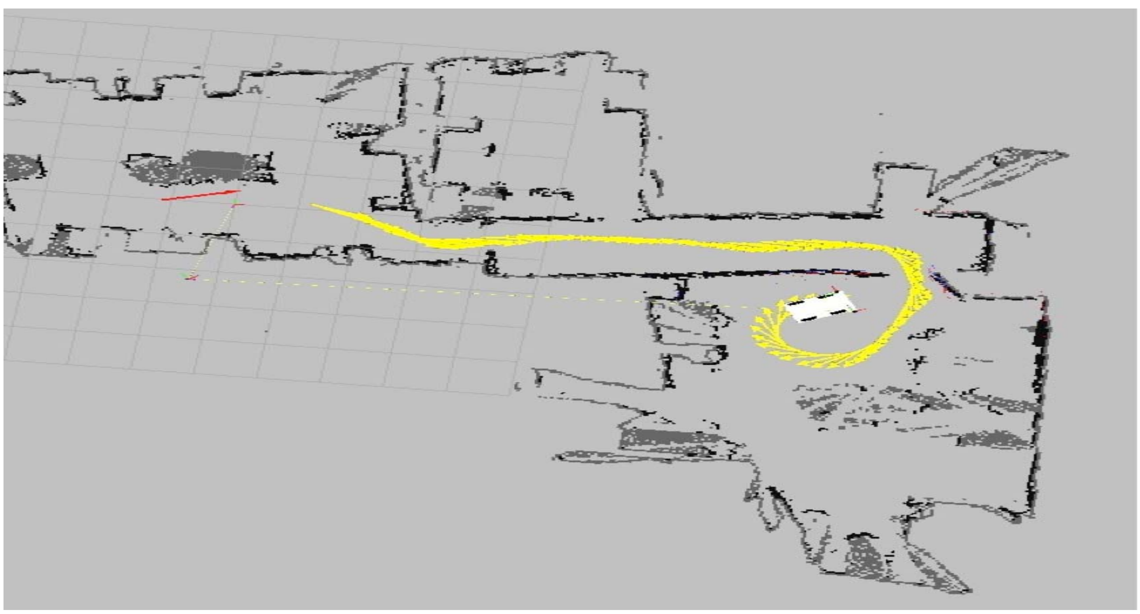

Fig. 7: Navigation with the grid map


[12] M. Quigley and K. Conley, "ROS: an open-source Robot Operating System," in *In ICRA workshop on open source software*, no. Figure 1, 2009.

[13] J. Mason and B. Marthi, "An object-based semantic world model for long-term change detection and semantic querying," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 3851–3858, Oct. 2012.

[14] R. Borja, J. de la Pinta, a. Álvarez, and J. Maestre, "Integration of service robots in the smart home by means of UPnP: A surveillance robot case study," *Robotics and Autonomous Systems*, vol. 61, pp. 153–160, Nov. 2012.

[15] R. Arumugam, V. R. Enti, K. Baskaran, and a. S. Kumar, "DAvinCi: A cloud computing framework for service robots," *2010 IEEE International Conference on Robotics and Automation*, pp. 3084–3089, May 2010.

[16] J. Schulman, A. Lee, and I. Awwal, "Finding Locally Optimal, Collision-Free Trajectories with Sequential Convex Optimization," 2013.

[17] I. Lane, V. Prasad, G. Sinha, A. Umuhoza, S. Luo, A. Chandrashekaran, A. Raux, N. Ames, and M. Field, "HRI tk : The Human-Robot I nteraction ToolKit Rapid Development of Speech-Centric I nteractive Systems in ROS," *NAACL-HLT 2012 Workshop on Future directions and needs in the Spoken Dialog Community: Tools and Data*, pp. 41–44, 2012.

[18] F. Sadri, "Ambient intelligence: A Survey," *ACM Computing Surveys*, vol. 43, no. 4, pp. 1–66, Oct. 2011.

[19] S. Wang, L. Chen, H. Hu, and K. McDonald-Maier, "Doorway Passing of an Intelligent Wheelchair by Dynamically Generating Bézier Curve Trajectory," in *IEEE International Conference on Robotics and Biomimetics*, 2012, pp. 1206–1211.