JiaoLong 2015 Team Description Paper

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Abstract. Frontier-II is an autonomous robot for service robot application, it is low-cost with modularized architecture, and fixed with a laser range finder, PTZ vision sensor, Kinect and 6-dof manipulator. The activity of JiaoLong research team is related to autonomous mobile robot, image processing, sensor fusion and SLAM. In this paper we present the robot hardware and vision, localization, navigation, manipulation software of JiaoLong team for RoboCup@home competition in 2015. This is the 2nd time we take part in this league (the 1st time is RoboCup2008 in Suzhou, China), though we had attended MSL league for 3 times. We won the 4 championships of the @home League in RoboCup China Open from 2007 to 2010.

1 Introduction

JiaoLong team focuses on the development of service robot and its correlative technology. Frontier-I and Frontier-II robot are our products as autonomous mobile robot, so are the Omnicam06 of omni-vision system, the intelligent wheelchair and the safe manipulator as service robot.

We have been putting efforts in applying a number of Image Processing, Navigation, Localization, and Mapping Methods, which results in the continuous enhancement of our robots. Consequently, we won all the 2:2 championship of the Middle-Size League for three times since we participated in Chinese Robot Competition (CRC) (Shanghai 2002; Beijing 2003; Guangzhou 2004; Changzhou 2005). Recently, we also got second place in 2006 and the third place in 2007 in RoboCup China Open Competition (Suzhou and Jinan) for Middle-Size League.

The Frontier-I robot had participated in the RoboCup Competition in year 2003 (Padua Italy) for the first time, as JiaoLong Team on behalf of Shanghai JiaoTong University[1]. So we did for RoboCup 2004 (Lisbon, Portugal) and 2005 (Osaka, Japan). Then, in 2006 Nubot associated with us to make a mixed team for RoboCup 2006 MSL league (Bremen, Germany).

Now Frontier-II robot has prepared for the @home league in RoboCup. It is an update version from Frontier-I. We won 4 championships of the @home League in China Open from 2007 to 2010. Especially in @home League of China Open 2008 and 2009, we won championships both in General Application and Open Challenge. Although JiaoLong only got the 8th position in RobotCup 2008 (Suzhou, China), it would do better in 2015 (Hefei, China).

2 Frontier-II Robot Description

The Frontier-II robot is constructed at the Institute of Automation of Shanghai JiaoTong University as a part of a project to build autonomous mobile robots for the research and education on distributed multi-robot systems cooperation under dynamic and uncertain environment.

As an open mobile platform, Frontier-II has a modularized architecture. All the robot components are standard industrial aluminum frames. It is in size of 43×45×120cm with two differential driving wheels and a caster. It employs a Laser Range Finder (LRF), and two color cameras: Kinect and PTZ vision, as its main sensors to map building and obstacle detecting. A microphone is used to recognize human voice. A laptop computer is used for the task planning processor. A 6-dof robot arm is used to do object manipulating tasks.

The whole weigh of Frontier-II is 22kg include the LRF. We use an embedded PC as the lower level controller for the behavior based controller. An Inter-Process Communication (IPC) mechanism is introduced to realize distributed software design, which is used to get sensor readings and to provide motor output commands and communications packet control. The TI DSP TMS320LF2407A is adopted as a microcontroller, used for the motion control.

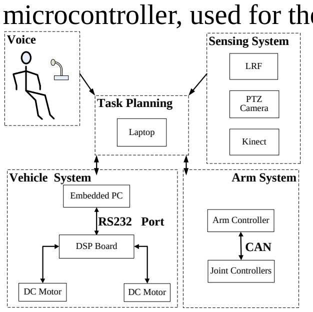


Fig.1 Frontier-II Architecture

Fig.2 Frontier-II Robot

3 Focus of Research Interests

3.1 Object Recognition Based on Vision

The object recognition system applied to Frontier-II robot is based on David Lowe's SIFT[2][3](scale invariant feature transform) algorithm, which is a robust feature detector. As illustrated in Fig.3, the recognition system is divided into two steps. First, at the off-line step, a model database is built up from various natural objects in the room environment, such as the table, desk, bed, door, etc. SIFT features are extracted from pictures of these objects, and later are organized and saved in a special format in order to improve the searching speed. The online algorithm extracts features from current scene, finds matching pairs against database, removes false matches, evaluates the matching performance, and finally outputs the recognition results.

Further more, our algorithm can also estimate the relative pose of the camera with respect to landmarks[4]. It can also deal with more than one objects (as shown in Fig.3) and gradient, partial, revolving, enveloped objects (as shown in Fig.4).

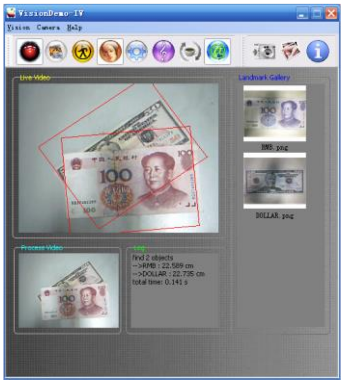
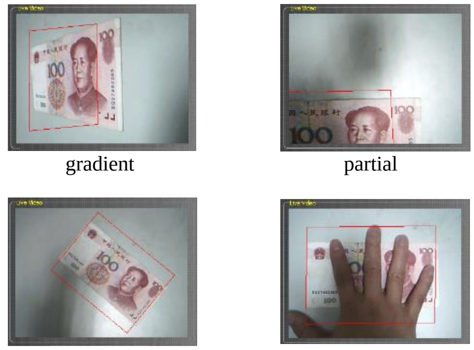


Fig.3 Two Recognized Objects



gradient partial

revolving enveloped

Fig.4 Different Postural Objects

3.2 Active Global Localization Based on Localizability for Mobile Robots (Main Research)

In global localization under the framework of a particle filter, the acquiring of effective observations of the whole particle system will be greatly effected by the uncertainty of a prior-map, such as unspecific structures and noises. In this study, taking the uncertainty of the prior-map into account, a localizability-based action selection mechanism for mobile robots is proposed to accelerate the convergence of global localization. Localizability is defined to evaluate the observations according to the prior-map (probabilistic grid map) and observation (laser range-finder) models based on the Cramér-Rao Bound. The evaluation considers the uncertainty of the prior-map and does not need to extract any specific observation features. Essentially, localizability is the determinant of the inverse covariance matrix for localization. Specifically, at the beginning of every filtering step, the action, which makes the whole particle system to achieve the maximum localizability distinctness, is selected as the actual action. Then there will be the increased opportunities for accelerating the convergence of the particles, especially in the face of the prior-map with uncertainty. Additionally, the computational complexity of the proposed algorithm does not increase significantly, as the localizability is pre-cached off-line. The results in paper[6] demonstrate that the proposed algorithm could accelerate the convergence of global localization and enhance the robustness against the system ambiguities, thereby reducing the failure probability of the convergence.

Taking account of the uncertainty of the prior-map, such as unspecific structures and map noises, localizability-based active global localization is proposed to accelerate the convergence of global localization. The algorithm is under the framework of classical PF[7][8] based on the PGM. The evaluation of the particle importance weight adopts the scan-matching algorithm[8][9]. The main improvement is the localizability-based action selection mechanism. Specifically, in every filtering step, all the possible robot actions are tested to see which one could generate the maximum localizability distinctness of the whole particle system. Then this action is selected as the actual one. The detail of localizability-based active global localization algorithm could be found in [6].

3.3 Manipulator System

The mechanical structure design for the assistive manipulator is shown in Fig.5, as well as the system modeling and design of the basic control system for the manipulator. As for the hardware design, in order to reduce the manipulator's weight while still keeping its high quality in mechanical performance, light-weighted material aluminum LY12 is applied for building the manipulator's mechanical structure. Motor control boards are connected by CAN bus to set a distributed control system. When it comes to software design, first the local coordinative systems for all six joints are set and along with their D-H parameters, the manipulator's kinematics, inverse kinematics as well as the differential inverse kinematics are calculated, based on which the robot's position motion control, speed motion control and path planning(point-to-point motion, linear motion and arc motion) are realized.

Based on the developed platform of the assistive manipulator, a multi-task finite state machine (FSM) is designed so as to control the manipulator to fetch objects, assist its user with his/her eating and drinking, etc. Besides, the proposed control method for constrained mechanism manipulation basing on impedance control and motion prediction is also applied to the assistive manipulator and it succeeded in opening a door of a common piece of furniture. Last but not the least, all the communications between the manipulator and human user are carried out via a multi-modal man-machine interface.

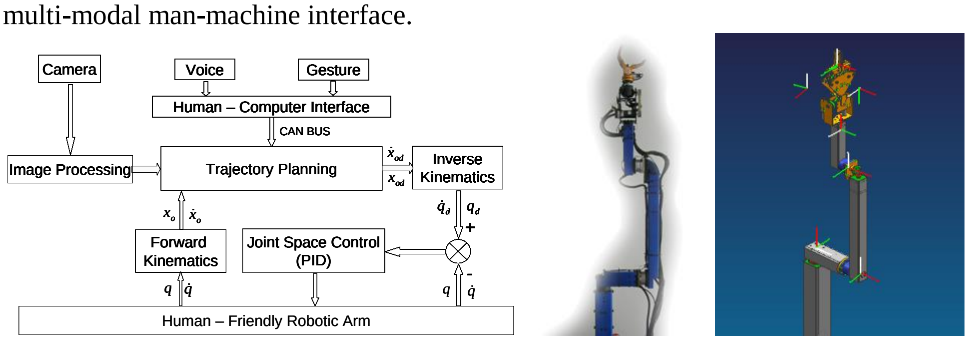


Fig.5 mechanical and control structure design for the assistive manipulator

Fig.6 shows the process of searching, grasping and fetching.

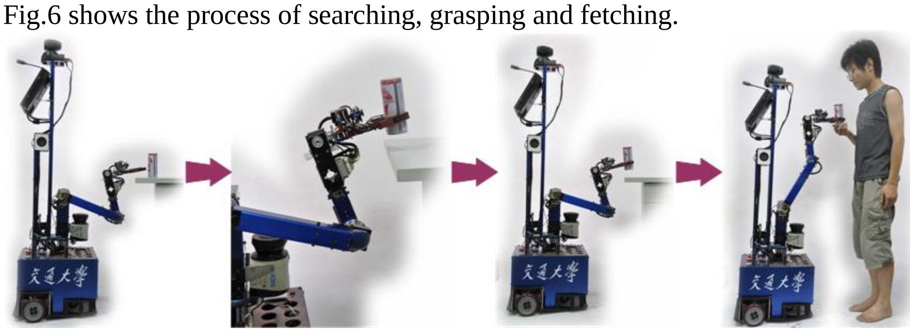


Fig.6 Object fetching process.

3.4 Manipulability Improving Scheme for Mobile Manipulating

The problem of mobile manipulating is very fundamental in domestic environments. In order to successfully achieve the mobile manipulating task, a manipulability improving scheme is proposed and investigated by JiaoLong research group. The scheme treats the vehicle and the manipulator as a whole system and can improve the manipulator’s manipulability during manipulating. And thus remedy the manipulator’s manipulability decreasing and/or joint variable’ abrupt change as well as the workspace limitations during manipulating. What’s more, the control scheme can drive the vehicle to move according to the end-effector so as not to collide with obstacles, and can manipulate smoothly. Firstly, the velocity of the end-effector is generated with the hybrid position/force control for manipulating, and then the coordinated motion control of mobile platform and the manipulator is adopted to drive the whole system moving to a suitable position to manipulate successfully. The control scheme can be used by any mobile manipulator that can be velocity controlled.

The block diagram of the control system is shown in Fig.7. The control system mainly contains three controllers, which are the translational controller, orientation controller and the coordinated motion controller that generates motion for the joint variable of the redundant system.

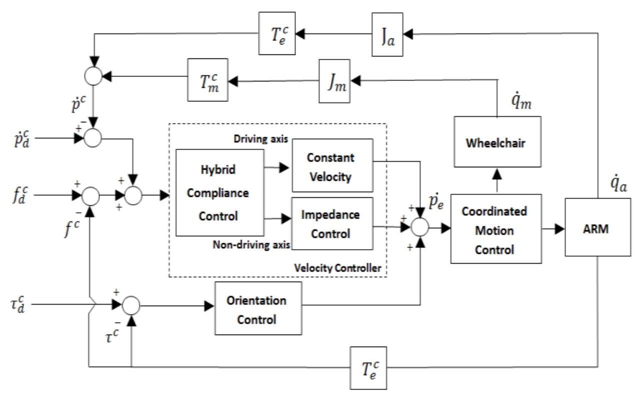


Fig.7 Block diagram of the control scheme

Where $\dot{p}_d^c$ is the objective velocity for opening the door that is expressed in constrain frame $\sum_c$. The term f_d^c and τ_d^c is the objective force and torque at the non-driving-axis respectively. Transformation matrix T_e^c and T_m^c transfer the manipulator’s end-effector frame and mobile platform frame to the constrained frame $\sum_c$.

The detail of manipulability improving algorithm could be found in paper[10].

3.5 Safety Design and Realization of Assistive Robotic Manipulator Based on Collision Detection

To make human-manipulator interaction safe, a method and its realization of safety design of assistive robotic manipulator based on collision detection is presented. The collision is detected by the difference of the reference torque calculated according to the dynamic model and the factual torque measured by torque sensor. In the design of joint torque sensor, the finite element analysis method is applied to optimize the pasted position of strain gauge, and then, signal processing circuit with high capacity of resisting disturbances is developed. According to the low speed characteristic of assistive robotic manipulator, a simplified dynamic model is established, which comprises the efficiency and accuracy of the calculation of reference torque.

Among various tasks expected to be performed by an assistive robot, operating a certain kind of constrained mechanism for its user is considered to be a major function. In daily living environment, a contact between the manipulator and the constrained mechanism could be of many kinds, a typical example is opening/closing a door or a drawer. In this paper, a novel method for operating an unknown constrained mechanism is introduced, utilizing a 6-DoF F/T sensor mounted on the manipulator's end actuator. Because the control method imitates the behavior of a human operating such mechanisms in a black room, it doesn't require pre-modeling of the target mechanism thus is highly adaptive and practical. Based on the spring-mass-damper model of a robotic arm and the force/torque date estimated by the F/T sensor, the desired motion direction of the manipulator's end-actuator estimated by rolling modeling could be adjusted and thus the actual motion direction of the mechanism in the coming control cycle could be estimated. In this way, the controller for the manipulation of constrained mechanisms is realized.

Through the collision experiments between manipulator and balloon, torque and speed deviation of each joint are analyzed. Fig.8 shows the experiment process respectively in low (10 Degree/s) and fast (30 Degree/s) speed.

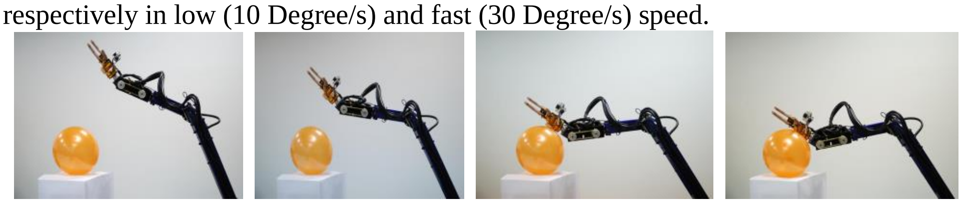


Fig.8 Process of collision experiment

The detail of this algorithm could be found in paper[11].

4 Applications

We developed 2 application prototypes for service robot: guide robots and an intelligent wheelchair for Shanghai Expo2010.

Fig.9 Guide Robots and Autonomous Intelligent Wheelchair for Shanghai Expo2010

More videos are shown in website:
http://robotics.sjtu.edu.cn/index.php?r=article/list&id=video

Frontier-II's Hardware Description

For our robot we are using the following Components:
-Sensor: SICK LMS111 Laser Range Finder, MicroSoft Kinect, Sony PTZ Camera
-Motor: Maxon DC Motor 70W(Mobile), Maxon DC Motor 10-70W(ARM)
-Motor Driver: Elmo SoloWhi.
-Onboard PC: Embeded PC + Laptop

Frontier-II's Software Description

For our robot we are using the following software:
-Platform: ROS in Ubuntu and VS in windows
-Localization and Navigation: Please refer to [6,8,12]
-Face recognition: Based on Adaboost.
-Speech Recognition and Generation: Microsoft Speech SDK.
-Object Recognition: SIFT
-Arm control: Please refer to [5,10,11]

6 References

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