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Mobile Manipulation for Everyday Environments

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Abstract: Robots are gradually being deployed for everyday environments, that is environments with no or very limited engineering taking place before deployment of the system. As manipulators and mobile platforms come together to deliver truly ubiquitous functionality the number of possible applications open up. The design of such systems require careful design of methods for navigation in dynamic environments, posture control, object recognition, visual servoing, grasp planning and integration. In this presentation a system for mobile manipulation in everyday environments will be discussed. The general design of the system will be outlined and the different component systems will be presented with a discussion of the alternatives for successful performance. Results from a real demonstrator system will also be presented to illustrate performance. Finally a number of challenges for the future in terms of basic performance, transfer of results and deployment will be presented.

Keywords: Robotics, Integration, Mobile Manipulation, Manipulation, Mapping, Grasping.

1. INTRODUCTION

One of the fastest growing sectors of robotics is in services. Over the next few decades the industrialized world will experience a significant aging. This will challenge the established healthcare system and associated social services. This far there has been significant progress on mobile robots for the home. The company iRobot has sold more than 3 million Roomba systems and a number of other companies are also entering this segment. It is characteristic that almost all the applications focus on mobility with little or no interaction with the environment. This true both for domestic and professional applications. There are quite a few new applications that opens up when a system is augmented with manipulation capabilities. Examples include fetch-and-carry, meal preparation, advanced cleaning (clearing a table), etc. In addition there are many professional applications that open up such as factory assistance - joint lifting, fetch-and-carry, mobile tooling, etc. It is thus an interesting challenge to consider how a robot can be equipped to have both mobility and manipulation. Important problems to study in the design of such systems include both navigation and obstacle avoidance for the mobile system and the traditional problems in manipulation in terms of control, object detection, grasp planning etc. There is also a need to consider joint control of the systems - i.e., mobile manipulation. In addition to the design of the overall system there is a need to consider how such as system could be implemented in a flexible fashion and such that it is easy to maintain and extend.

In this paper we will present a system for mobile manipulation that is based on a balancing Segway RMP 200 with a KUKA Light Weight Robot (LWR) mounted on top. The Segway has a payload of 100kg and a max speed above 3 m/s, so more than adequate for safe navigation in an indoor environment. The KUKA Light Weight Robot is a prototype system that is due for market release. This is a 7 DOF arm with a weight to payload ratio of 1. The arm is based on a design from DLR [1]. The arm is controlled through a standard industrial controller with an command rate of 85 Hz, the joint controllers are running at 4 kHz. The arm has built-in force and torque sensors in every joint. The combination of a Segway with a LWR was organized to study true mobile manipulation. In many setups it is possible to design a system for "move then manipulate" operations where there is a clear separation between the mobility and the manipulation part. When mounted on a mobile platform that is balancing this option is not possible and one is forced to consider mobility and manipulation as an integrated problem. The system has an on-board SICK LMS 291 laser scanner and a firewire camera mounted on the Schunk gripper. A picture of the system is shown in figure 1.

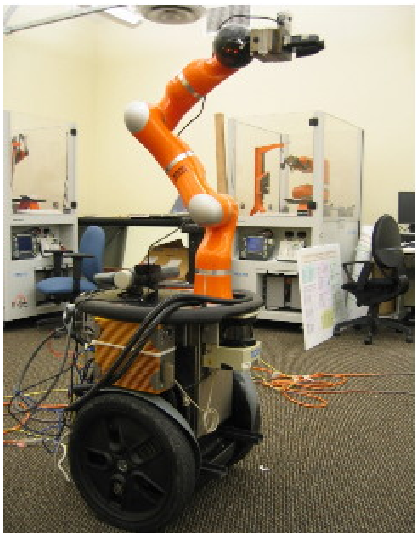

Fig. 1 The Segway RMP200 with the KUKA LWR mounted on-top. The mobile manipulation system considered here.

We will present the overall system design in Section 2. Example experimental results are discussed in Section 3. and finally a number of open problems and general conclusions are presented in Section 4.

2. SYSTEM OUTLINE

The task considered here is the prototypical task of "fetch-and-carry" where a mobile robot is required to drive to a known location and pickup the object for delivery. In practical terms the following tasks have to be solved:

1. Mapping of the environment
2. Localization
3. Obstacle Avoidance
4. Training for new objects
5. Detection of known objects
6. Pose estimation of object
7. Grasp planning
8. Trajectory planning for the arm
9. Grasping
10. Arm/Platform control/coordination

Each of the tasks are briefly described below.

2.1 Mapping

For the present application it is assumed that the area of operation is a limited size space, say 10x10 m or similar. We further assume that it is relatively simple in spatial layout. It is clear from a spatial analysis that there is a need to localize the robot with an accuracy of about 5cm. Given the accuracy the arm can easily grasp selected objects. Considering the application constraints a suitable approach to mapping is through use of an evidence grid [2], [3]. The laser data are feed into an evidence grid with a resolution of 5cm.

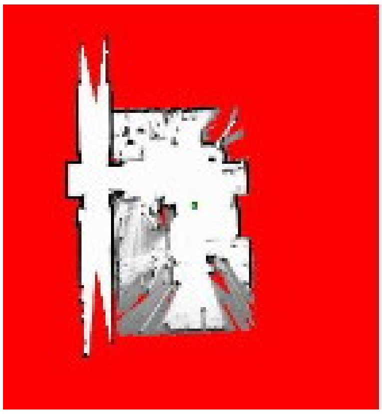

Fig. 2 Example Grid Map from the Workspace

2.2 Localization

As the map is an evidence grid the localization is performed probabilistically using a particle filter for matching to the evidence grid, as detailed in [4]. Again the data are based on use of the laser scanner. Given that the pose of the Segway may include leaning, i.e. it might not be upright, the laser data are projected into a horizontal plane before matching. The Segway might lean as much as 10 deg which introduces an error of upto 2%.

2.3 Obstacle Avoidance

The system is expected to operate in an area where other agents might be present and in addition the environment might change after a map has been acquired. To handle this the system includes a module for obstacle avoidance. In open spaces in the map, i.e. in regions that are marked as open a difference analysis is performed to detect possible cells that are occupied. If a certain number of cells (> 2) are occupied the area is considered an obstacle. To handle this a potential field approach [5] is adopted. For each obstacle a force component is generated and the resulting force from multiple obstacles is computed by superposition.

2.4 Navigation

The robot will be required to goto particular locations that are specified in the map "pickup cup from the kitchen counter", where "kitchen counter" is a specified region in the map. To drive to a location a distance transform is used [6]. Across the set of open cells in the map the distance field is computed and a greedy search returns a path to the goal. The path is traversed sequentially but may be perturbed by the obstacle force mentioned above. The selected path specifies a local force in the direction of the path and any obstacle force is used superimposed.

$$F_{drive} = F_{path} + F_{obstacle}$$

The approach is effective for relatively open spaces but poses a challenge in cluttered spaces due to the existence of local minima.

2.5 Training of new objects

The set of objects is not pre-defined. For each new object the system has to handle an object type is specified. At present box- and cylinder-type objects can be processed. For box type objects a fronto-parallel view of each face is required. For cylindrical objects 3 curved face views and the top view are required for training. The system computes a saliency map for the faces and within the object boundaries SIFT features [7] are computed for pose estimation.

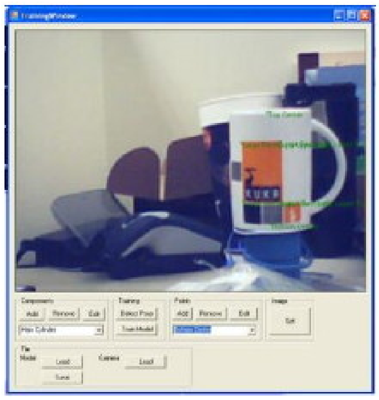

Fig. 3 Example training for a cup

2.6 Object recognition

The recognition of an object is performed by execution of the saliency detector to prime the recognition and within salient regions the SIFT detector is executed to search for correspondence. The object is detected and tracked using a particle filter [8] as shown in figure 4.

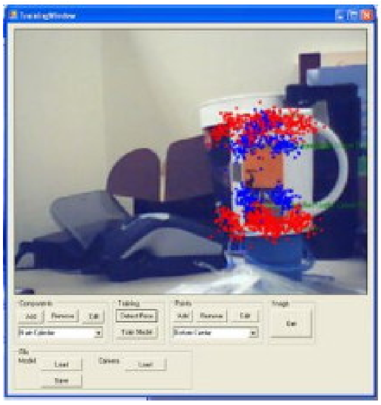

Fig. 4 Example of detection/tracking of object using a particle filter

2.7 Grasp Planning

Given the set of possible object types the grasp planning is relatively simple. Once a robot has arrived in an area and an object has been localized the possible set of grasp are evaluated. In many cases several of the potential grasps are outside the work-envelope of the system and they can easily be discarded. The closest stable grasp is then selected for execution. In the current implementation the grasp analysis is entirely kinematic, but current work is trying to expand it to include dynamics [9].

2.8 Arm/Platform Coordination

There are two possible way to coordinate the arm and the platform motion. The Segway has a standard balancing mode that can be used and one can move the arm freely and assume that the platform will compensate for changes in the location of the center of mass. Unfortunately this is not a very effective control model. Alternatively one can change the control to be full integrated. We have done this using a non-linear control model in which the dynamics of the two platforms is considered to be in competition and an attractor system is setup to organize the control. The control approach is described in a separate paper [10].

2.9 Coordination

The overall coordination of the system is performed by a centralized controller that manages the process. The process is described as a state-flow process. The motivation for such a model is that it easily can be augmented for error processing and recovery. The state-flow is relatively straight forward. The process is shown in figure 5.

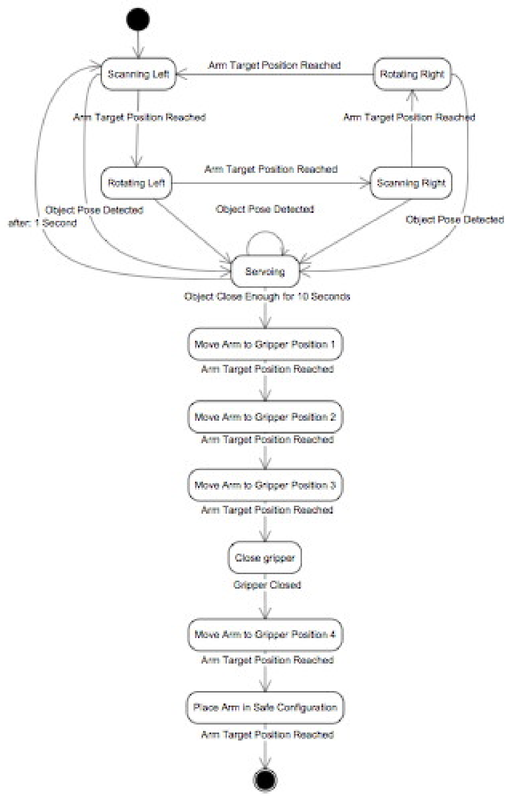

Fig. 5 The state flow for the mobile manipulation task

3. EXPERIMENTAL RESULTS

The full system described in Section 2.has been implemented using Microsoft Robotics Studio (MSRS). The motivation for using MSRS was primarily to evaluate the utility of the package for real-world tasks. We have performed a communication benchmark of MSRS (v 1.5) that indicates that process cycles upto 400 Hz are easy to achieve and under ideal conditions it is possible to achieve cycles rates beyond 1 kHz, but due to the non-real-time nature of Windows XP there will be outliers that might seriously impact performance. For our application we have organized a setup where Segway control is a separate service. For the KUKA LWR we have designed a service that utilizes the KUKA Remote Sensor Interface (RSI) for specification of joint values. The RSI interfaces communicates with the RSI interface every 12 ms which is adequate for simple control.

The overall systems architecture is shown in figure 6. Each of the processes are implemented as a service in MSRS.

All of the services were implemented in C# and ran on a single CPU system. The system uses a 1.8 GHz Dual Pentium and had 1GB Ram. The computer system was responsible for image processing, navigation, arm control, etc. The final system ran with an overall frequency of 8 Hz, which is adequate for smooth navigation and for interaction with the arm. Both Windows XP and Windows XP Embedded were evaluated but with no significant performance difference. The system has been systematically tested across 20 different scenarios to determine the performance of the system. The details have been reported in [11].

If less than 10 cm space is available around the robot it might fail to achieve it mission. In addition for certain types of objects the grasping was not consistent. The

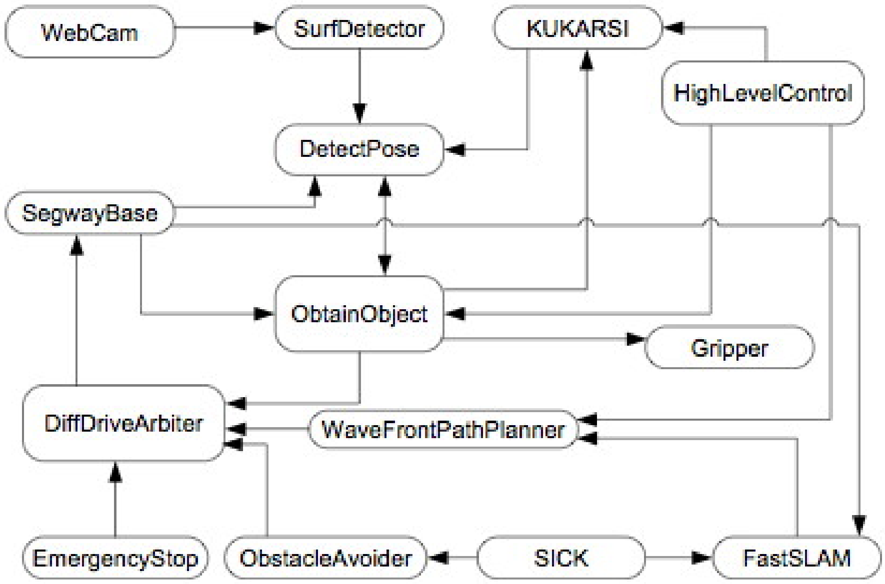

Fig. 6 The process architecture for the mobile manipulation system

lack of reliable grasping is primarily due to the fact that the hand has no tactile feedback, consequently grasping control is purely feed-forward.

4. SUMMARY

In the present paper we have briefly outlined a system for mobile manipulation. The system was designed for execution in everyday environments so it has facilities to handle changes in the environment layout, the presence of other mobile agents such as people, and significant variation in illumination. The system is capable of doing mobile manipulation for fetch-and-carry type tasks. It includes facilities for automatic acquisition of new object models and easy re-training for deployment in new environments. The system is designed to be highly modular so that it is easy to replace a particular module as new methods become available. Through use of the Microsoft Robotics Studio and its associated set of service contracts it is relatively easy to exchange methods, for say a new navigation technique. At the same time the methods are easily portable to other platforms. As an example the navigation methods used for the Segway/LWR system has recently been moved to another platform. The other platform uses a Hokuyo laser scanner and it is a fully holonomic platform. Without any changes the code the navigation and obstacle avoidance was deployed on this other platform. As mentioned earlier we have also used two different approaches to arm/platform integration, one based on simple balancing and another based on modelling using non-linear dynamic systems [10]. Due to the modularity it was easy to evaluate both approaches as it simply requires replacement of a single service within the system.

The present system provides an example of the type of performance that can be achieved today. Obviously the system has limitations. First of all the navigation system relies on a laser scanner that considers the world to be 2D. There is here a general need for the community to consider obstacle avoidance in 3D and preferably in a world that is dynamically changing. Object recognition for a limited number of objects (< 25) is by now a relatively well understood problem especially if the objects have some surface texture. For hand-arm coordination the dynamic systems approach has a lot of promise. It provides a framework that has a solid theoretical basis. The issue of safety for operation in everyday environments was not addressed here, but it essential to consider. Finally the grasp modelling and integration with haptic sensors is essential for reliable execution.

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