KeJia Robot–An Attractive Shopping Mall Guider

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Abstract. This paper reports the project of a shopping mall guide robot, named KeJia, which is designed for customer navigation, information providing and entertainment in a real environment. Our introduction focuses on the designs of robot's hardware and software, faced challenges and the multimodal interaction methods including using a mobile phone app. In order to adapt the current localization and navigation techniques to such large and complex shopping mall environment, a series of related improvements and new methods are proposed. The robot is deployed in a large shopping mall for field test and stable operation for a fairly long time. The result demonstrates the stability, validity and feasibility of this robot system, and gives a positive reward to our original design motivation.

Keywords: Shopping mall guide robot · Localization and navigation · Mobile interaction · Quadtree mapping

1 Introduction

With the rapid advance of robotic technology, several well-known robots have been developed, with cool appearance, human-like joints and more intelligent behaviors, such as Willow Garage's PR2, Boston Dynamics' Atlas and the Meka. However, the general public rarely have the opportunities to interact with the tangible robots despite that these "stars" represent the latest techniques and indicate the future trend.

In this paper, we apply our robot named KeJia to a day-to-day shopping mall scenario, in which KeJia is implemented as a shopping assistant providing route guidance and information service. Nowadays, the size of shopping malls is becoming larger and larger, usually hosting hundreds of individual commercial tenants. The new customers (sometime even the regulars) get lost in the complex and maze-like environment, not to mention finding the desired locations. Even though floor maps are provided, customs usually prefer to seeking for manual guidance. Besides, there is a strong demand for such a device that

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can provide product catalogs and discount information once customers enter a shopping mall. In order to improve the shopping experience and service quality, the shopping mall managers trend to hire more professional guiders, resulting in a large financial burden.

Against this background, KeJia is devised to guide the customers to right locations as required autonomously and provide information to them by natural language. Furthermore, the robot itself can attract more people and bring a fresh feeling to the shopping mall. Apart from the aforementioned features, KeJia system also contains mobile apps that can extend the robots to simultaneous service. By integrating the concept of cloud technology, it's convenient for the users to acquire the desired information from the robot remotely through their mobile phones.

2 Related Work

In the past decade, one of the most popular applications is to deploy the robots as tour guiders in museums, expositions or other public places. The earliest work was carried out by [1], the robot RHINO acted as a guider in the "Deutsches Museum Bonn" for six days and provided service for more than 2,000 visitors. The robot MINERVA [12], a successor of RHINO, had better performance in navigation and interaction. In [5], the robot Robotinho addressed the challenge on more intuitive, natural and human-like interaction, unlike the previously works, which mainly focused on localization, automatic navigation and collision-free avoidance in populated environments. Although these robots are running reasonably well, their operation environments are almost completely known, neither of museums or exhibition halls. What's more, the size of the operation environments is usually limited to hundreds of square meters, which means the unexpected situations that are lethal to the normal travel of the robots would be greatly reduced. In contrast, as for the shopping mall scenario, there are still many challenging problems need to deal with.

The shopping mall is a more frequently visited place in routine activities, and some studies have already concerned with robot systems in such scenario. Most of them try to design a shopping trolley for helping the elderly, the sick, or the disabled. In [11], the task of RoboCart is to carry the purchased goods and lead the way for impaired customers in a grocery. With distinctive expectation for shopping assistant, we hope robot could perform like realistic clerk, not a porter. Some other interesting researches provide difference functions to assist customers. For example, [13] developed a remote shopping system, where the robot grasps the products(i.e., goods with various textures, shapes and weights) on the shopping lists using telemonitor with a special manipulator. The system proposed by [10] and [8] are most similar to ours, [10] presented an interactive robot that is fixed at a place in the shopping mall, giving directions by speech and gestures. The robot TOOMAS [8] roams in stores to search the potential customers and then guides them to the target locations. However, their main limitation of most of them is that the robot can not execute any movable navigation behaviors.

Most of the aforementioned approaches are proof-of-concept prototypes and have not been completely deployed in real shopping malls. With a few exceptions, they have conducted field trials, but required extra environmental modification to facilitate the deployments of robot systems. In more details for localization and navigation, RFID tags often need to be installed in the workspace in advanced, which may be troublesome and inflexible. Moreover, such deployment need to be redo once the environment changes. Although the robot TOOMAS is a exception of this case, its operating environment (shown in a picture in [8]) is more like a supermarket fulled with structured shelves, rather than a shopping mall that has lots of independent shops. In a real shopping mall, wide range of unpredictable changes exist due to the shop decoration, temporary stalls, advertising board replacement, infrastructure improvement, etc (see Fig. 1), it's the key challenge for robot navigation and customer guidance. Besides, we use a mobile app to enable the communication between the robots and users, which is a new feature for shopping mall robot that is quite effective as confirmed by our deployment.

3 Features and Hardware

3.1 Key Features

Shopping mall is typically a collection of all kinds of shops where customs can buy their daily necessities (e.g., clothes, shoes, foods, restaurants, etc.). The size of a large shopping center is often more than tens of thousands of square meters and has high flow rate of customers. Given this, the key features of our intelligent assistant shopping robot are fellows.

(1) *Providing Information*: For the customers who are busy, they would like to know whether they can buy what they want quickly. The robot can response to instant enquiring and provide information in more natural ways. Additionally, it can give specific recommendations and introductions according to different inquiries.
(2) *Shopping Guidance*: A robot, moving in front of the customers, can guide them to the right shops, which providing pleasant shopping experience for the costumer. It can also avoid time-consuming and aimless search for people who don't enjoy the process.
(3) *Advertisement and Recreation*: From the views of the shop owners and mall managers, the robot can attract more customers to boost their sales. In fact, the advertising effect of robots exceeds traditional methods (e.g., posters, billboards). Some people even come to the shopping mall just for interaction with our robot. Withal, people enjoy chatting with the robot for recreations.

3.2 Hardware

The robot KeJia designed for the shopping mall scenario is shown in Fig. 2, which is a derivative of KeJia Project[2]. It is worth pointing out that a prototype with the similar hardware design has won the championship in the 2014

Robocup@Home competition. The appearance of KeJia is a young lady, dressed on a traditional suit. With the height of 165 cm the robot is comparable to a professional shop assistant. Unlike other shopping robots [8], the touch screen is not adopted due to the following considerations. Firstly, it's not convenient for people to operate the touch screen while robots are moving. Secondly, our speech recognition provides fairly accurate results with the directional microphone equipped. Thirdly, mobile phone Apps provide additional method to interact with robot. A sound equipment embedded in the base is used to play the voice generated by speech synthesis module. The whole robot is motorized by two differentially actuated wheels on the middle axis and a castor on the rear. This offers KeJia a good maneuverability and stability. The main sensor of the robot is a HOKUYO UTM-30LX laser scanner, which feeds the distance data of obstacles around the robot(maximum distance 30m) to other software modules(e.g., navigation and localization).

Fig. 1. (a) Typical shopping mall channel (b) new added resting chair (c) glass wall (d) temporary stall

Fig. 2. (a) KeJia robot (b) laser scanner (c) base (d) differential wheels

Inside the clothes, hides a frame made by aluminium alloy and plastic shells, which constitutes the body of the robot. The two arms and the head are fixed on the interior frame. The arms with four DOFs can make simple gestures like greeting to people, and the two DOFs head can freely turn to face to the people if necessary. All of these make KeJia look more realistic.

4 System Architecture

4.1 Top-Floor Structure

Our system could consist of several distributed robots, which can interact with people face-to-face by voice or thought the mobile client, and a cloud server connected to Internet. As shown in the Fig. 3, robots are deployed on different floors in the shopping mall, configuration data centrally store on the server where

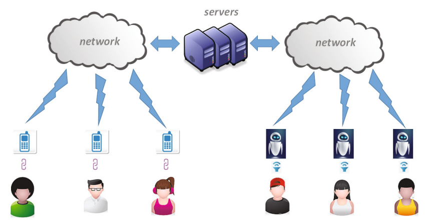

Fig. 3. Concept map of the proposed system

robot could conveniently download from. It's advised to inquire and command the robot by speech if the customers are nearby, additionally, the app installed on the smart phone is able to send the typed text or recorded sounds to the server and then forward to the robot, after processing, the response data of the robot will transfer back over the same way. There are some advantages of this structure, firstly, it's convenient to modify the configuration information which is constantly changing, what the robot need to do is regularly to update the latest data from the server. Secondly, different interaction methods make the robot reach its greatest potential at the same time, other people can still keep "chatting" with robot during navigating period by mobile phone.

4.2 Software Modules Structure

In our system, we adopt a flexible four-layered software architecture (see Fig. 4) to meet the requirements of a integrated robot system, such as reliability, extensibility, maintainability, customizability. The lowest layer is the Robot Operating System [1], which provides a set of robotic software libraries and reliable communication mechanism for modular nodes. The second layer mainly contains hardware drivers, thereinto, the laser and camera drivers are in charge of packaging the raw sensor data to standard format and then publish them to upper layers, the motor and audio drivers interpret the messages from upper layers to hardware for executing. The next layer is the most important one in the structure, all the proper skills of a classic robot are placed here, such as mapping, localization, navigation, people tracking, speech recognition and synthesis, which directly decides what the functionalities would be implemented in the upper applications. The highest level is responsible for task managing, configuration data updating, dialog managing and robots' state updating. The background server collect the real-time robots' state (i.e., coordinate, task state) and forward to the smart phone app. The dialog manager module attempts to understand the users' intentions and dispatches tasks.

By using such layered structure, for a new application or adding a new skill only the corresponding layers need to be changed rather than the whole system, and individual module can be assigned to different programmers who just develop the desired functionality according the preestablished interface without caring other's implementation details.

[1] http://www.ros.org

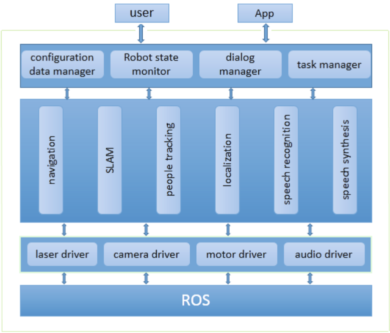

Fig. 4. Four-layered software structure

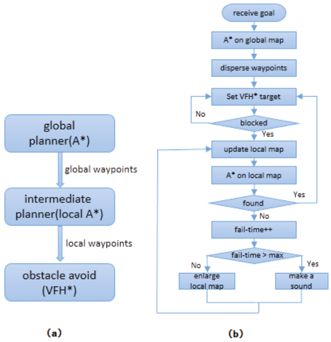

Fig. 5. (a) Navigation structure (b) flow chart

4.3 Methods to Challenging Modules

In this section, we will present expatiation to these modules that are faced with technical challenges.

Mapping of Large Environment. There are already many mature algorithms to the simultaneous localization and mapping(SLAM) problem[4,9], most of them take the grids map as the representation of environments. However, the memory exhaustion problem emerges along with the increasing enlargement of mapped environment, especially for particle filter family, in which every particle is generally associated with an individual map. The size of the shopping mall is usually more than 10,000 m^2, which makes the situation worse, therefore a new map representation is introduced as quadtree map. A quadtree is a tree-based data structure that is capable of achieving compact and efficient representation of large two-dimensional environment. We re-implement the Rao-Blackwellized particle filter SLAM[7] by replacing traditional grids map with quadtree map (for more details, see [3]).

Localization in Complex Environment. Accurate localization is the prerequisite of safe and credible navigation behaviour. Under the shopping mall circumstance, there are some problems must be considered in order to achieve excellent performance, including dense streams of people and undetectable obstacles caused by the characteristic of the laser sensor. In fact, transparent glass walls exists in everywhere of modern shopping malls, they just can be perceived at certain angles from the laser. To overcome those thorns, we modify the likelihood model based on the AMCL[6][2] by multiplying a weight with the score indicated the matching degree between the map and the laser beams. The weight value is assigned to each map cell using a custom editing tool manually, the value

[2] Open source page: http://wiki.ros.org/amcl

of cells belonging to permanent obstacles likely solid walls are greater than these representing glass walls.

Navigation. The biggest trouble with navigation in shopping mall is the wide range of unpredictable changes that have been mentioned at the end of Sec.2, robot can't perceive these changes until approaching. In the previous researches, navigation module combined global planner and local planner is introduced for this case, global path replanning will be triggered when robot traps in local dilemma. But this idea is not fully applicable for us since it may lead robot repeatedly alter its route in vain. In reality, the passages are often temporarily blocked with customers, it would not be the best choice for robot to replan every time for the following reasons. 1) The robot may move back and forth between two blocked passages frequently without progress. 2) Re-finding a global path on the whole map is time-consuming. 3) Making a long detour sometimes is expensive than just waiting for a while. In order to eliminate this disharmony between global and local planner, a intermediate layer is employed.

Once a goal is receiving, firstly, the path from the robot's position to goal is computed. Next, a serial of ordered way points are generated from the global route, then the way points will be sequentially dispatched to the local planner which will find a local path for the well-tuned VFH* module[14] to track. If local planner fails to find a suitable path, the local map would continue enlarging until a maximum limit reaches. After several failures, robot will demand the crowd to give way, if all these attempts fail, a global replan happens. This approach endows the robot ability of adapting the shopping mall environments, meanwhile, reduces the unnecessary global path plan (shown in Fig. 5).

Multimodal Interaction

(1) *Speech Dialog System*: The sentences outputted by speech recognition system are divided into two classes, depending on whether they fall into the domain. The customers can have some conventional talk understood by the robot, like asking the robot to give an introduction or recommendation. In case the robot is caught off guard by the sentences beyond the domain, an inner chatting module is designed, which provides amusing and interesting talk though they maybe meaningless to the input sentences. This method has a good effect and avoid awkward situations.
(2) *Phone Application*: The phone app in our system is an inventive interaction style, which can do the job formerly belonging to speech recognition by typing or recording. The map of the mall, the robot's position and available destinations are shown in the application on the mobile phone screen, gives customers freedom of choice, and the collected data of customers' options also give the criterion of recommendation.
(3) *Other Recreations*: To enrich the robot's behaviors, we develop a "greet guests" mode, the robot will stand at a shop's door, say "hello" to the comer and "goodbye" to the leaver by detecting the movement of the customers with laser data.

5 Results of Field Trials

Our filed trials last for about 40 days from December 2014, including 10 days of preparative debugging work. The shopping mall where our robot deployed is the largest and most prosperous one in the provincial capital city, it has 4 floors gathered with nearly 300 commercial tenants and our robot works on the first floor with size of more than 10,000 m^2.

The first step to deploy this robot is building the environmental map, in order to collect the laser data and odometry data for mapping, we operate the robot to stroll along all passageways in the ground floor of shopping mall with a wireless joystick. The sensor data streams into the particle filter SLAM algorithm which is improved by integrating quadtree map representation. The final built map is shown as Fig. 6, the size of the map is $205m * 68m$ with resolution of $0.05m$. By using the quadtree representation, such a considerably large map only costs 10.80 MB internal memory and 287.1 KB disk space.

Fig. 6. (a) Quadtree map of the shopping mall (b) map used for localization and navigation

In order to be suited in practice, we modify the map for constrained path planning with black mask areas(shown in the Fig. 6 (b)), which are usually the interior of shops and not passable for robot. While for localization, the original map is used to make the laser data matched as good as possible. The Fig. 7 (a) shows a global path based on static map from start point(brown) to end point(red), the (b) shows an intermediate planner within the local map windows(square box $3.5m * 3.5m$), the path planned in this level is not exactly the same with global path because the new surroundings have been taking into account, and it's the key that our system can handle wide changes in the environment.

Customers in the shopping mall are free to choose one of the two interactive methods–talking by speech or mobile app. In the face-to-face mode, customers' sentences are recognized and then passed to dialogue manager module, once the intentions are explicit the robot will begin a tour guide (shown in Fig. 8.(a) (c)). Customers also can talk with KeJia by pressing the microphone icon and the text displays on the screen, the shops' positions are drawn on the map with

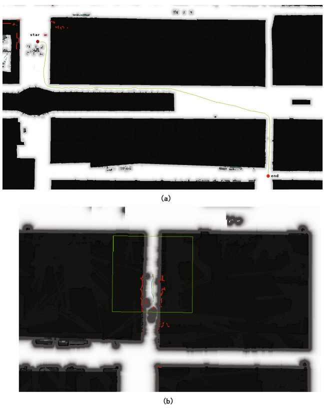

Fig. 7. (a) Global path (b) the blue line is path planned by intermediate level, the green line is part of global path

Fig. 8. (a) Talking with customers (b) chatting with app (c) during a tour guide (d) map in the app, red dots are shops, blue dot is robot

red dots, they can be chosen as goals by touching. In general, the mobile app provides a straightforward and effective graphical interface for users.

During the whole operational period, totally about 150 complete tour are performed, and the accumulated distance is more than 7.5km. KeJia can provide trouble-free service with success rate of 75%, the most common reason of failure is losing its position, this often results from the crowded or some obstacles that can't be perceived by the laser. The customers seem to be more interested in chatting with robot by mobile app, they intentionally say some sentences that can't be handled by KeJia and expect it to respond with funny jokes.

6 Conclusions

From this project of KeJia robot, firstly, we have proved the reliability and effectiveness of proposed robotic techniques, including layered software architecture, mapping in large indoor area, localization and navigation in complex environment and module integration. Secondly, the mobile phone app provides another quick and convenient way to communicate with robot, and it becomes the most often used and acceptant way with the customers in actual running. Lastly, from the practical operation results, we can see that the general public have intense interest in robot and demand for everyday use, and we hope our work could provide some experience for similar robotic application.

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