CoBots: Collaborative Robots Servicing Multi-Floor Buildings

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I. Research Overview

In this video we briefly illustrate the progress and contributions made with our mobile, indoor, service robots CoBots (Collaborative Robots), since their creation in 2009. Many researchers, present authors included, aim for autonomous mobile robots that robustly perform service tasks for humans in our indoor environments. The efforts towards this goal have been numerous and successful, and we build upon them. However, there are clearly many research challenges remaining until we can experience intelligent mobile robots that are fully functional and capable in our human environments.

Our research and continuous indoor deployment of the CoBot robots in multi-floor office-style buildings provides multiple contributions, including: robust real-time autonomous localization [1], based on WIFI data [2], and on depth camera information [3]; symbiotic autonomy in which the deployed robots can overcome their perceptual, cognitive, and actuation limitations by proactively asking for help from humans [4], [5], and, in ongoing experiments, from the web [6], [7], and from other robots [8], [9]; human-centered planning in which models of humans are explicitly used in robot task and path planning [10]; semi-autonomous telepresence enabling the combination of rich remote visual and motion control with autonomous robot localization and navigation [11]; web-based user task selection and information interfaces [12]; and creative multi-robot task scheduling and execution [12]. Furthermore, we have developed a 3D simulation of the multi-floor, multi-person environment which will allow extensive learning experiments to provide approximate initial models and parameters to be refined with the real robots' experiences. Finally, our robot platform is extremely effective, in particular with its stable low-clearance, omnidirectional base. The CoBot robots were designed and built by Michael Licitra, (mlicitra@cmu.edu), and the base is a scaled-up version of the CMDragons small-size soccer robots [13], also designed and built by Licitra. Remarkably, the robots have operated over 200km for more than three years without any hardware failures, and with minimal maintenance. Our robots purposefully include a modest variety of sensing and computing devices, including the Microsoft Kinect depth-camera, vision cameras for telepresence and interaction, a small Hokuyo LIDAR for obstacle avoidance and localization comparison studies (no longer present in the most recent CoBot-4), a touch-screen and speech-enabled tablet, microphones and speakers, as well as wireless signal access and processing.

The CoBot robots can perform multiple classes of tasks:

- A single destination task, in which the user asks the robot to go to a specific location— the **Go-To-Room** task— and, in addition, to deliver a specified spoken message— the **Deliver-Message** task;
- An item transport task, in which the user requests the robot to retrieve an item at a specified location, and to deliver it to a destination location: this **Transport** task also acts as the task to accompany a person between locations when the item to transport is a person.
- A task to escort a person to a specified location, the **Escort** task, in which the robot waits for a person in front of the elevator on the floor of the destination location, and guides the person to the location.
- A semi-autonomous telepresence task, the **Telepresence** task, in which users may request to be remotely present on the mobile robot with autonomous navigation and obstacle avoidance. Users select destination points on the map or on the robot image view to move to remotely through the telepresence web interface. Furthermore, they can control the robot through a rich motion and perception-controlled web-based interface [11].

The above tasks are equivalent from a navigational point of view, as they are achieved by the same navigation planner generating plans to reach destinations in the building. A task planner generates different interaction plans for each task and its symbiotic autonomy needs.

We are currently focusing on several research directions: multi-modal speech interaction, interactions among our multiple robots, learning from human demonstration, human observation, and human correction. We continue to investigate depth-based camera 3D image processing for object and person detection and person following. We further investigate robust execution monitoring, and active learning for learning of the environment and effective factored human-robot interaction plans.

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II. Video Content

We organize the video from 2009 to the present.

a) 2009: The initial CoBot in 2009 (later named CoBot-1), was designed to serve as a visitor companion robot.[1] CoBot guides the visitor through the building according to the visit's schedule. The robot plans its path between locations and provides information about the places and hosts in the visit, both taking the initiative and responding to requests [4]. For its autonomous localization and navigation, CoBot-1 used the signal strengths of WiFi access points [2]. As we realized that the robot would inevitably have limitations in localization accuracy, even if seldomly, we introduced from early on the concept of symbiotic autonomy, in which the robot would proactively ask for help from humans when its localization uncertainty was high [4], [10]. CoBot could navigate and effectively avoid obstacles on a single floor of an office building, with multiple long corridors with different flooring (carpet, tile, and slate) and handling different wall construction materials (cement and dry wall) which interfered differently with the WiFi data. The portion of the video for 2009 is of low quality as we did not collect better video at that time.

b) 2010: In 2010, CoBot moved to a new building, quite rich from an architectural point of view with glass walls and bridges, non-straight turns in corridors, different flooring, and wide lounge areas. CoBot-2 was completed, which included a powerful pan/tilt/zoom camera which was used for web-based telepresence [11]. CoBot-2 has attended meetings on behalf of remote users, who could effectively communicate and move around physically in the environment. We developed Corrective Gradient Refinement (CGR) Localization, a novel localization algorithm which uses CoBots LIDAR [1]. Furthermore, CoBot escorted visitors at a crowded open house, demonstrating its robust obstacle avoidance and navigation capabilities.

c) 2011: In 2011, we opened a website where users could schedule tasks on CoBots, such as sending messages, escorting visitors, and making deliveries [12]. The robots have completed hundreds of user tasks, such as delivering mail, collecting printouts, and sending messages. A few of these tasks are shown in the video.

We also added functionality for CoBots to ride the elevator with human help [5], another application of symbiotic autonomy in which robots and humans collaborate to complement one another's shortcomings. We developed a 3D simulator for the CoBots, which will be used for larger scale testing than is possible in the physical world, as well as for rapid prototyping and testing. Furthermore, we extended CGR localization to use the Kinect RGB-D camera [3]. The Kinect is much cheaper than the LIDAR sensor it replaced, bringing indoor robots a step closer to feasible deployment.

[1]We used the initial CoBot term standing for Companion RoBot, which we later changed to meaning Collaborative RoBot due to the subsequent introduction of symBiotic autonomy as a collaborative relationship with the humans in the environment. The term "cobot" has been used in a variety of research projects, in particular in an early robot manufacturing helper. We basically use the term for its general good sounding. Collaborative robots have also been recently termed co-robots.

Finally, we have created an algorithm for CoBot to find and search for arbitrary objects in the building using the web [6]. The central idea behind this research, as with symbiotic autonomy, is that we recognize the limitations of robots as they currently are and devise strategies to work around these limitations with human help (or with human-generated data, in this case) rather than setting the issues aside and limiting the robots to the lab or strictly controlled conditions.

d) 2012 and Beyond: In 2012, CoBot-3 and CoBot-4 were completed. CoBot-3 is being used offsite for telepresence. Both are much quieter than CoBot-1 and CoBot-2, but retain the same basic design.

The CoBots continue to be available to users daily. As we continue to increase the functionality and robustness of individual CoBots, we are beginning to explore the potential of multiple CoBots. In three years, we have made great progress towards our goal to deploy multiple robust and reliable robots in an office building, building upon the past 25 years of research by the robotics community.

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