Proceedings of the 13th IFAC Symposium on
Information Control Problems in Manufacturing
Moscow, Russia, June 3-5, 2009

A decision framework for operation management of reconfigurable mobile service robots in hospitals

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Abstract: This paper describes the decision framework for managing a group of reconfigurable mobile service robots, built to help the health care personnel in their logistic activities that range from medicine delivery to virtual consultation to spillage cleaning to surveillance patrolling and environmental monitoring. A formal model describes the operation of the robotic system. A decision framework is proposed for operation management of the robotic system including configuration, location, power management of robots and mission allocation and real time control. Finally a linear programming approach is proposed for configuration, location and power management of robots. Numerical experimentation is conducted to show the limit of such an approach.

Keywords: Mobile service robots, Healthcare, Decision Framework, Operational Research.

1. INTRODUCTION

Due to progress of medicine and the evolution of demography, most of the OECD countries are considered as aging societies, where the percentage of elderly people is increasing. In order to overcome the upcoming shortage of workforce, most industries are relying on robots to fill the gap. According to the estimation of International Federation of Robotics, the number of operational industrial robots is over one million and will surpass the 1.2 million by 2010. And the number of service robots sold will reach 5.6 millions units. One of industries most threatened by workforce shortage is the health care sector that is affected by both the shortage of skilful personnel and the high demand of health care service. IWARD is an on-going three-year project that explores the use of mobile service robots to attend health personal in their daily activities. The goal is to develop a system of mid-size mobile robots that can be equipped with additional modules, connected through a failsafe communication network, coordinated by some distributed/hybrid control strategies, and capable of performing different types of missions/tasks in the hospital context and in order to optimize some key performance indicators. Plug and play technologies will be developed such that modules can be easily inserted and removed from base robots by nurses or healthcare personnel without the need to reprogram the robot or the modules.

Based on a preliminary study of hospital requirements and specification, IWARD targets six types of missions to be handled by the robot including (i) delivery of medicines, notes, X-rays and personal items, (ii) regular and unplanned cleaning of patient rooms and spillage, (iii) guidance of patient/visitors inside a hospital, (iv) patient monitoring and patient-doctor teleconferencing, (v) hospital surveillance and (vi) environmental monitoring**.**

The aim of this paper is to give a global vision of operation strategies of the mobile robot platform for efficient assistance in the day-to-day basic nursing and logistic activities of a health care system within the competencies of IWARD robots.

Decisions raised in the operation of such a robotic system includes (i) configuration and location of different robots according to the needs of the hospital, (ii) assignment of scheduled and unscheduled missions/tasks to different robots, (iii) power management, (iv) mission assignment and (v) mission execution As a result, our work can be divided into three levels (i) strategies for joint location, configuration of swarm robots and power management, (ii) centralised operation strategies for task scheduling and allocation in order to best meet the requirements for assistance of the whole healthcare system over time, and (iii) distributed control strategies of swarm robots by using appropriate negotiation models and distributed decision making schemes. Those decisions were divided into three levels accordingly to the different nature of data used at each level and the time horizon for which the decisions to be taken.

There are many research initiatives on swarm robotics and coordination of swarm robots. For example, Reinaldo et al. (2002) used ACS algorithm to coordinate a set of task, Torres et al.(2006) studied the task distribution among a set of robot. However existing swarm approaches do not apply to our case due to limited number of mid-size robots, the failsafe communication, both planned and unplanned missions, needs to performance a variety of missions at the same time.

The following paper is organised as the following: Section 2 introduces a overview of the problem in form of a formal model, Section 3 presents the decision framework and finally Section 4 proposes a linear programming model for joint configuration, location and power management of robots.

2. FORMAL MODEL

This section presents a formal model describing characteristics of different components and missions relevant to operation management of the robotic system under consideration. The robotic system is composed of a set of base robots, different functional modules that allow base robot to have different configurations, a set of home stations for idle robots, a configuration and recharging station. The operating environment is described by a static map and a dynamic map. The system faces different planned or unplanned missions. The remainder of this section describes characteristics of these components.

2.1 Base Robots

A base robot is a basic platform on which different functional modules will be mounted on. A base robot is formally characterized by the following attributes: (i) a unique identifier of the base robot, (ii) the base type, (iii)the default speed and the maximum speed of robot, (iv) battery capacity and the power consumption rate in both active and standby mode,(v) the recharging speed of the battery. The information concerning battery capacity and the power consumption rate of the base robot can be either based on data provided by the manufacturer or learned on-line from historical data.

2.2 Functional Module and Configurations

One of the main characteristic of the IWARD project is the modular aspect of the robots, where the different modules can be easily plugged and unplugged on the robot. Each of those modules provides one or more functionalities like: routine cleaning, spillage cleaning, environment monitoring, virtual consultation, patient guidance and transportation.

The relevant characteristics can be summarized to the following: (i) a unique identifier of each module, (ii) the set of different functionalities provided by the module, (iii) power consummation rates during a mission or in a standby mode and (iv) hardware constraints and conflicting modules.

For each type of base robot, the set of all possible configurations will be defined with respect to the type of base robot, the number of modules that can be mounted on each base robot, and the compatibility of different modules In our project, an exhaustive enumeration of all the possible configurations is performed to identify all possible configurations.

2.3 Home Station

Home stations are the places where the robots return after finishing their missions, and wait in standby mode for the arrival of other missions.

A home station can be modelled using the following data: (i) a unique identifier of the home station, (ii) the location of the home station, (iii) the maximum parking capacity or the maximum number of robot that can be parked in this home station in the same time, (iv) in the case of continuous recharging, docking stations can be added to home stations in order to give the robot the possibility of recharging while waiting. In IWARD project, continuous recharging of robots is not considered.

2.4 Configuration and recharging station (C/R station)

Each robot needs to be reconfigured on a shift basis, to meet the changing demands and requests. Further, when the battery of a robot dries up, the robot should head tot the C/R station for a full recharge. Functional modules of a recharging robot can be removed and used to equipped other base robots. This place can also be used as a storage area for unused functional modules.

The main characteristics of the C/R station are: (i) the unique identifier of the C/R station, (ii) the location of the station, (iii) the number of available robot chargers, (iv) the maximum number of robot that can be hosted in this station

2.5 Static and Dynamic Map

The role of the static map is to identify different salient locations and the connection graph describing the paths between different locations and their distances.

A location is defined by the following attributes: (i) a unique identifier of the location, (ii) its coordinates X , Y and Z (iii) the name of the location and the related medical department of the location.

During the day some path can be filled with persons which decrease considerable the speed of the robot trying to avoid collisions, thus a dynamic shared map is being kept up-to-date, in order to informs the others robots on the traffic status of the different paths, the location of each robot and their destination.

2.6 Missions

Different mission types are considered: (i) spillage cleaning, (ii) routine cleaning, (iii) patrolling surveillance, (iv) environmental monitoring, (v) guidance, (vi) delivery, (vii) virtual consultation, (viii) robot recharging, (ix) other.

A mission type can be modelled using the following data: (i)a unique identifier of the mission type, (ii) a list of required functional modules, (iii) a list of missions that can be executed in parallel by the same robot.

Note that we assume that all missions are single robot missions, which means that a mission only requires a single