Robot Based Logistics System for Hospitals - Survey

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ABSTRACT
This paper is a survey on autonomous hospital logistics systems. We present commercial products that are successfully installed in hospitals and research projects proposed by various researchers from around the world. Such systems include mobile robots that need to navigate and safely move in a human populated environment. These robots are specially designed to carry various goods that need to be transported. Autonomous hospital logistics systems can include also user interfaces, mission planners, delivery and pick-up stations, parking and charging stations or special designed carts. We describe and compare the various approaches and systems functionalities. We specify the main problems and challenges that need to be considered when designing such systems. The innovative approach that could be an efficient solution for hospital transportation is also presented.

1. INTRODUCTION
There exist several commercial products that are successfully installed in hospitals [1], [6] or [23] and there are many projects that are currently progressed in research groups around the world [2] or [4]. It is proved and tested that autonomous delivering improves the efficiency of the hospital transportation [1], [6], [12] or [16]. Special analysis in [16] showed that installation of 6 robot units reduces the annual cost by approximately 56% and improves turn-around time performance by 33%. Implementing such a system brings several advantages:

1. It is cost efficient.
2. Robots never get sick, do not need holidays and work also in weekends.
3. Robots are predictable and do not make human mistakes.
4. An autonomous system can work 24 hours 7 days per week.
5. Hospital personnel can focus on patients.
6. Transportation tasks could be scheduled and done in the night shifts.

There are many items that could be transported on robot’s body within hospitals: medicines, medical devices, specimens, food, shopping, documents, waste, etc. Özkil et al. [15] made a deep study on things that are transported within the hospitals every day. Goods are divided into groups and authors presented estimated amount that are transported every day and with quantity of personnel that are needed for this reason. Other aspect of hospital transportation is to carry carts that could contained linens, laundry, meals, etc.

This is still a challenge to introduce mobile robots for maneuvering safely and fast in human populated environments such as factories, offices or hospitals. The problem of mobile robot delivery in highly populated environment is widely described in [10]. In [22] a list of the topics that need to be considered when designing a robot-friendly hospital was presented. Designing such a system involve the knowledge from several areas, such as: project management, mechanical technology, control systems, artificial intelligence or communication networks.

This paper goes through existing systems and solutions and it describes the state of the art in the hospital transportation. There is a list of challenges that need to be considered when designing such complicated system. We believe that our survey will be helpful for all of the researchers that would like to design a robot based logistic system for hospitals. Hada and others [10] presented the state of the art in robot navigation in human populated environments. Several examples of systems that provide transport in hospitals can be found in [15]. However there is no available work that goes through approaches of serving the autonomous transportation within the hospitals.

The rest of this paper is organized as follow: section 2 presents the main challenges that could be met, when designing robot-based logistics systems for hospitals. The third section describes the functionalities of existing commercial products and research projects. In section 4 the innovative approach to hospital logistic systems is presented.

2. CHALLENGES
Hospital environment brings many constraints that system need to fulfill. In [5] problems and challenges for transporting in such environment are pointed. Authors of [18] present requirements that every autonomous system need to fulfill to transport goods within the hospitals.

Nowadays not too many new hospitals are built. Therefore it is more required to design a new autonomous system that can be adopted to an existing hospital environment, than to design autonomous system and then design a new hos-
pital that can fulfill such system requirements. The main challenges, when designing robot-based logistics system for hospital, are:

- **Safety** - When robots are sharing space with people, the safety is the first thing that need to be considered. We have to be sure that robots would not collide with people and would stop or safely pass the obstacles on its way.
- **Obstacle detection** - How to place sensors on a robot platform and which sensors should be used to achieve detailed area scan around the robot.
- **Map of the environment** - How to build a map.
- **Path planning** - How to plan the path to go from start to destination point.
- **Follow the path** - Keep the preplanned path and make sure that robot will reach the final destination.
- **Navigation** - During the motion it is needed to know continuously the position and orientation of the robot. The easiest way is to install artificial landmarks. However in some cases it is not allowed to place extra landmarks. In environments like hospitals it’s preferable to install as less extra points as possible. Navigation using only natural landmarks (walls, lamps, corners, etc.) brings new challenges.
- **Robots need to navigate in narrow environment.**
- **Organize logistics** - How to organize the cooperation between robot units and supervisory system. How to organize ordering the tasks.
- **Each mission should be monitored and system should be still working if one of the units fails.**
- **Automatic use of doors and elevators** - System should be able to control doors and elevators and use them without human interfere.
- **Wireless communication** - How to plan the network, where place the access points, etc.
- **Installation of the robot charging and parking stations.**
- **Installation of the pickup/delivery stations.**
- **User interface** - This is important that interface is easy to use and that a proper request is send later to the task-scheduling server.
- **Stable transportation** - Goods like meals or specimen demand very stable carrying. Random people should not have access to the transported items.

Next section 3 goes through existing commercial products and research projects. It is presented how various systems deal with listed challenges.

3. **EXISTING SYSTEMS AND SOLUTIONS**

3.1 **Commercial systems**

There exist several commercial systems that are known and which are already successfully installed in the hospitals. Below we present examples of such systems, their functionalities and main features.

![Figure 1: HelpMate robot](image)

3.1.1 **Helpmate**

Evans in [6] presented the system technologies embodied in HelpMate (see Figure 1). HelpMate works as follow:

1. Hospital personnel (operators) place the goods in a special designed shelves installed on robot’s platform.
2. Operator selects a destination or destinations from the map displayed on robot GUI (Graphical User Interface).
3. Robot is building a mission plan (a path to go).
4. Robot starts to go to destination on preplanned path. If meets an obstacle, robot tries to go around and if there is no path to go then robot is waiting till obstacles will be removed.
5. When goods are delivered, a person that receives them, needs to confirm that mission is finished.

Each robot has its own mission plan and path to go. There is a simple supervisory system that helps when two or more robots compete for critical resources such as elevators or narrow corridors. In [5] more detailed information of HelpMate navigation can be found. This robot uses odometric system [7] and natural landmarks (hallway walls) due to the continuous position estimation. The robot can transport unscheduled meal trays, lab, pharmacy supplies or patient records. On doors and elevators are installed special control computers that robot can communicate with through an infrared transceiver. The map is generated by the installation engineer via an off-line special designed application. Robot has a flashing warning light and emergency STOP on its body. At the beginning of the project ultrasonic sensors, lights in front and bumpers were installed for obstacle detection. HelpMate example shows that such system could be continuously improved corresponding to the technology novelties. In [21] last updates about the product and short commercial history are described. In the last system version light sensors have been replaced with a laser scanner for more detailed area scan and to achieve more efficient obstacle avoidance function. HelpMate was one of the first products that served the robot transportation within the human populated environments and it is treated as a pioneer in autonomous systems for hospitals. Nowadays HelpMate is a registered trademark of Cardinal Health, Inc. but there is no information available about current product status.
3.1.2 Swisslog

Swisslog developed a TransCar AGV (Automated Guided Vehicle) system for carts transportation [23]. It includes a flat robot (see Figure 2) that is going under the carts, lifts them and delivers to the desired position. The operator places a cart in a pick-up station and enters a destination on a wall-mounted terminal. Then, all of the transport activities are handled automatically. There is no information available if it is possible to schedule a task that will be executed automatically.

To install this system in the hospital, the environment needs to fulfill many needs. List of the topics that should be considered when designing a hospital is presented in [23]. The advantage of this system is that the robot can carry on its body most of the cart types. The only requirement is that the trailers need to be wide and high enough that the Swisslog robot could go under them. Therefore, there is no need to buy new carts and the system could be adopted to the trailers that already exist in the hospital. An disadvantage of this system is that it cannot carry simple items on its body such as medicines, documents, food, etc.

3.1.3 Hospi

The Matsushita’s Robotic Blood Sample Courier System [25] consists of a group of autonomous mobile robots (see Figure 3). The system is designed to control blood samples delivery and other transportation tasks within the hospitals and the laboratories. The main computer assigns various tasks to individual robots who pick up blood samples, deliver them to automatic analyzers, and collect the samples after testing. Robots detect obstacles through a laser scanner and can provide a free of collision path. Matsushita’s system includes a group control system that monitors robot missions, solves failure situations, controls robot’s batteries level, etc. (full list [25]). Each vehicle unit is equipped with a positioning mechanism that provides high precision in specimen pickup and delivery.

3.1.4 Aethon

Aethon designed an automated system for transporting and tracking hospital goods [1]. There are two developed robot systems: TUG (see Figure 4) and HOMER. TUG robot transports a special designed cart within the hospitals. The functionality of carts transportation is similar to the Swisslog system 3.1.2. Robot is a flat unit that goes under the carts, lifts them and safely delivers to the selected place. There are several types of designed carts and they are divided based on the items that they are transporting. There are following carts: central supply, nursing, pharmacy, lab, medical records, dietary, linens. Each cart is designed to provide most efficient and safe transport for its item type. Carts are equipped with touch screen, basic control buttons and electronic locks. TUG robot is equipped with light sensors to detect obstacles on its way. HOMER is the RFID-based (Radio frequency identification) asset management solution that can locate hospital equipment. HOMER robot runs around the hospital and checks (through reading RFID labels) if equipment such as beds, wheelchairs, carts, etc. are in the right place. HOMER cooperates with TUG system. When one of the items is detected in the wrong place and it is possible to transport it by TUG robot, then the TUG robot gets an order to move this item to the proper position.

The disadvantage of this system is that robot can transport only specific carts. It increases the costs of the system installation and requires more changes in the hospital logistics than for example in the Swisslog system, see 3.1.2.

3.1.5 SpeciMinder

CCSRobotics provided an efficient specimen delivery system [20]. The robot’s (see Figure 5) autonomous features are based on MobileRobots [13] technology. This system allows robot to navigate without artificial landmarks. Upon
installation, the robot builds a map of the environment and later uses this map for planning the mission. In this system the request of delivery is made on robot’s body interface. User places the items on the robot and then select a destination. When the task is done robot goes back to its station. An disadvantage of this system is that items and tasks can not be scheduled. SpeciMinder is successfully installed in Delaware Hospital in the United States.

3.1.6 Commercial products summary

The summary of the commercial products is presented in Table 1 and in Table 2. The collected information is based on the referred articles and commercial products descriptions. In some cases it was not possible to find specific facts or available information were not enough to specify the feature status. In such situations a ‘not available - na.’ status was declared. In tables we included also a RobCab system, which is described more detailed in Section4.

Description of transportation functionalities:

- Specific goods transportation - robot is designed to transport only specific goods on its platform (meals, blood sample, etc.)
- Varied goods transportation - robot is able to carry any goods that are placed in a special box on/in its platform.
- Carry carts on its body - robot is designed to go under the carts, lift them and next transport to the desired place.
- Tow the trailers - robot can grab a trailer and tow it to wanted position.

Description of logistic systems features:

- Group of robot cooperation - robots are working as a fleet of units, they can share an environment sources in a scheduled order.
- Supervisory system - Supervisory system plans, schedules and sends the mission plan to the specific robot that executes the mission. Each robot and mission can be monitored on-line.
- Ordering on robot’s platform - robot is equipped with GUI, which allows the personnel to define a task.
- Ordering through logistic system - personnel define a task through logistic system. GUI could be placed at any place in a hospital that has connection to the logistic system.
- Task scheduling - tasks can be scheduled off-line and set to specific time. Tasks could be repeated with desired frequency.
- Automatic elevator service - elevators can be controlled by autonomous system.
- Artificial landmarks - it is needed to install artificial landmarks for navigation needs.
- System installed in hospital - system is successfully working at least in one of the hospitals.

3.2 Research systems

In this section we present several research projects that propose autonomous logistic systems for hospitals. Main aspects are described and characteristic features are pointed and commented.

3.2.1 FIRST

FIRST (Friendly Interactive Robot for Service Tasks) [18] is another mobile robot system to transport carts within the hospitals. During 3 months installation in hospital at Clamart near Paris system features were tested. However there is no information if nowadays it is working at any hospital. Development of this project is presented in [4]. The system could be divided into:

- Ground Station - acquiring missions from the operators, scheduling missions, assigning missions to robots, path planning, supervising missions, etc.
- Robots - transporting goods along predefined paths and safely maneuvering around people.

One of the advantages of this system is a function to simulate mission plans for each robot. When mission is planned and scheduled, first it is simulated in order to emulate the fleet of robots in an automatic mode. Thanks to this a behavior of robots can be predicted and it can be ensured that there will be no conflicts in real world.

3.2.2 i-Merc

A group from Technical University of Lisbon, developed a mobile robot system to deliver meals inside health services [2]. To perform the service they designed the robot called i-Merc. This robot is equipped with heating system to keep temperature of meals and prevents bacteriologic proliferation. It provides more hygienic and efficient meal transportation and is able to deliver personalized diets. First stage of this project with a service concept and virtual and physical prototype is described in [2]. Authors focused on the transportation meals from the kitchen to the patients’ rooms and returning the respective soiled dishes safely. Chassis structure analysis which could be useful when designing a new robot is also provided.
Carreira et al. presented in [3] fuzzy controller model [26] and simulation results for i-Merc. Robot is able to deliver meals and navigate between start and destination point. Since authors in [2] were more focused on the developing the structure of the system and in [3] on navigation, there are many aspects in this system that were not considered or just mentioned. Areas like map building, localization, power management, sensors placement or safety motion would need further developments.

### 3.2.3 Other projects

The authors of [8] presented a system that uses florescent lamps on the ceiling of the corridors as natural landmarks to localize a robot position and orientation. The robot uses single camera to capture images of the lamps. This robot, in opposite to other robots described in our paper, has holonomic ability to move in any direction without changing orientation. Structure of ordering the task is similar as in 3.1.1 or 3.1.5. Touchscreen interface is installed on the robot's platform. User places the items to transport in the locker and selects the destination from the map. Then robot plans the map and starts to navigate in order to reach the destination point selected by operator. System has been tested in the laboratory and in the Prince of Wales Hospital in Hong Kong.

Hada et al. [10] introduced an advanced AGV (Automatically Guided Vehicle) that can work not only in hospitals but in any populated environment, such as offices. They also described the design policy, methodology, implementation and experimental results. Navigation is solved by using iGPS (indoor Global Positioning System) server [9], which tracks the robots within the area covered by cameras. This mean that only for navigation needs there is a need to install many cameras in the environment where the robot is going to maneuver. The authors of [10] presented also the man-robot interface, which allows to request a delivery and also monitor the progress of the requested task. Delivery task-scheduling server is divided into three parts. It allocates the request to specific robot, manages the execution of primitive task sequences and controls the elevator operating devices. Such elevator’s manipulation device consists radio control servos that operate the elevator by pushing the buttons. However this solution is not so practical and nowadays there exist much more common wireless solutions, such as in described products [23], [1] or [20]. Mobile robot in this system follows its path and stops when sensors detect an object on the path. Robot waits 5 seconds and checks if the object is still there, if yes then robot tries to avoid it if there is enough place. The disadvantage of this solution is that robot might be stuck in one place for longer time, when still there is a place to go. It is necessary that people would collaborate with robots, and would change their position if they stay on robots path. Experiments show that there still is a need to improve navigation system. Since when people cover the iGPS cameras, robot has a problem to position itself by using only odometric system[7].

Özkil et al. proposed in [15] a system that consists group of
robot units, automatic stations and special designed containers for automation transportation of goods in hospitals. The overall system structure is described and necessary modifications in hospital infrastructure are also presented. Robot in this system is a part of a group of robots that are controlled by remote server that control also elevator service. There are three modes of transportation: shuttle - transporting goods from one station to another. Bus mode - enabling to coverage of multiple stations in a defined route. Taxi mode - transportation upon request. Robot similar to system presented in 3.1.4 carries special designed containers on its body. Each container has an embedded transponder. Stations are equipped with a pneumatic lift to provide automatic loading and unloading containers from the robots. Supervisory control system plans the route of the robot in order to fulfill all scheduled deliveries and avoid conflicts that result from different user requests. Beside main supervisor on each robot is installed local interface, that in case of the failure of the wireless communication can take responsibility of collecting the orders. For localization purposes several reflectors are placed in the routes as landmarks, which help robots to correct their positions. Several access points for wireless communication are placed around hospital. Tests in Bispebjerg hospital showed that some modifications need to be done to improve system infrastructure.

Shieh and others [19] presented Intelligent Hospital Service Robot (IHSR). Personnel of different departments of the hospital order items through internet. These orders are collected by staff of chart room and next the items are placed into the robot. Next operator of the robot enter the detailed tasks into robot system and robot starts to execute its mission. System had been tested in a simulator.

In a system proposed by Takahashi and others [24] a patient puts his or her personal belongings on trays. These trays are stored in a special tray racks and robot goes back and forward between patient and the tray rack. The idea of this project is that patients would be able to store their private belongs in a special selected place and not only in a small box close to the bed. Robot follows guide lines that are placed on the floor or ceiling. In the paper authors present also a guide how to place such lines, which robot treats as landmarks.

4. INNOVATIVE APPROACH TO HOSPITAL LOGISTIC SYSTEMS

The RobCab AB from Västerås started the project to develop a mobile robot system for transportation within the hospitals. Robot will be able to carry goods on its body, tow the trailer and move safe and fast in the human populated environment with and without the trailer. Implemented algorithm has been tested on testing platform (see Figure 6) in a hospital like environment. An example scenario could looks as follow:

1. Nurse at floor 5 orders several items from the hospital supermarket (floor 1) through friendly interface. Nurse selects that items should be delivered to the station number 13 (Station13).
2. Supermarket’s employee collects the order, places the items in the station (Station7) and confirms that goods are collected.
3. Supervisory system receives an order, plans and schedules a mission and sends a mission plan to the robot that at current moment would execute such a mission with a minimal cost. Lets called this robot Penguin2.
4. Penguin2 receives the mission and starts to execute it. Firstly goes to the Station7, automatically collects the goods and places them in a locked box.
5. Penguin2 goes to the elevator and supervisory system calls the elevator.
6. When elevator arrives Penguin2 checks if there is a free area inside and enters.
7. Supervisory system sends the elevator to fifth floor and when it arrives Penguin2 leaves the elevator and goes to the Station13.
8. In a meanwhile Supervisory system receives an order that a trailer with the dirty linens (TrailerA) needs to be transported from a parking place (PlaceP) at floor 5 to the laundry in a basement. Supervisory system collects an order and plans and schedules a mission. Since it is known that Penguin2 will soon finish his current mission close to the PlaceP, Supervisory system sends a mission plan to Penguin2, who puts a mission in a queue.
9. Penguin2 leaves the items at Station13, sends a confirmation to the Supervisory system and starts to executes next mission.
10. Penguin2 goes to the PlaceP, docks to the TrailerA and grabs it.
11. Penguin2 pulls the TrailerA, enters the elevator and exits it in a basement (elevator control is the same as in the case when going without a trailer).
12. Penguin2 delivers the TrailerA to the laundry station, sends a confirmation, goes to the one of the empty charging stations and waits for the next mission from the Supervisory system.
From above scenario it could be concluded that this same robot unit is able to carry goods on its body and tow a trailer. An extra capability that makes this system more complicated than others described in this paper is a function to drive with a trailer. Mobile robot when towing a trailer is a highly nonlinear model and control such a model is not a trivial thing [11], [14], [17]. This is one of the biggest challenges within this project. Robot needs to deliver a trailer to the selected parking station and safely maneuvers around people. Moreover there are also other technical aspects that need to be challenged: detection a type of the trailers without placing the landmarks, precise grabbing and releasing the trailers, stable connection when moving or obstacles detection around the trailer.

RobCab’s system includes also other main functionalities that autonomous system should fulfill, which is pointed in Table 1 and in Table 2. The system pilot installation in one of the hospitals is planned at the end of the year 2009.

5. SUMMARY AND CONCLUSIONS

This paper describes the main challenges that could be met, when designing a robot-based logistics system for hospitals. The existing systems, solutions and state of the art in the autonomous transportation within the hospitals has been presented. The innovative approach has been also described. In the future work we want to develop a presented RobCab system and finalize the pilot installation in one of the hospitals.

6. REFERENCES


