HelpMate®: A Robotic Courier for Hospital Use

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Abstract **TRC has successfully introduced automation in hospitals via HelpMate, a robotic courier. HelpMate has been designed to perform fetch and carry tasks while exhibiting human like behavior as it navigates down crowded hallways in the hospital. The tasks typically performed by the robot are carrying late meal trays, sterile supplies, medications, medical records, reports, samples, specimens and mail. HelpMate is able to traverse along the main arteries of hospitals, crossing between the buildings using interconnecting corridors and elevators. Odometry based navigation is enhanced by sonar, infrared and vision sensors which aid in obstacle detection and avoidance maneuvers. The fail safe design is complemented by both non-contact and contact sensing. A map of the hospital is made available to HelpMate, from which, it is able to generate a path from any location in the hospital to any other destination.**

An extremely simple human interface has been specially designed for this application. The on board screen, emergency stops, warning lights, turn signals and pause buttons provide easy and quick interaction with the system. The dispatch/receipt interface requires only knowledge of the task to be performed and demands no previous experience with either computers or robots. Four major functions may be performed using this interface, round trip dispatches, one way trips, one way trips with stops and rounds. A complete self diagnosis done upon power up coupled with run time diagnostics ensure system integrity.

I. Introduction

In the United States today, hospitals are under pressure to reduce the cost of the healthcare they provide. Reduction of services to patients can only be taken to a certain level before basic patient needs are not met and healthcare is unacceptable. Many hospitals are about to reach this point and cannot cut costs further by simply reducing staff. Furthermore, the problem is aggravated by a critical nursing shortage [1][2].

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Automation can increase staff productivity and allow more patient interaction, however, automation has largely been applied to only the functions of data processing, data acquisition, and laboratory analysis.

These factors of patient need, cost reduction pressure, a nursing shortage, and limited automation provide a significant opportunity for new forms of automation. Studies on staffing shortages in hospitals show that transportation tasks take up a considerable amount of staff time. A robot that can perform transportation tasks could therefore relieve hospital personnel of this time consuming, secondary task and free their time for the more critical primary duties. With this concept in mind, TRC has developed HelpMate, a robotic courier capable of navigating crowded hallways and riding elevators to deliver payloads to programmable destinations throughout a hospital.

II. The Hospital Environment and Tasks

The HelpMate perceives a hospital environment as a network of stations, hallways, elevator lobbies, and elevators. Multiple buildings pose no problem provided there are interconnecting hallways. A "station" can be any location in a hospital (that is accessible by the robot). Typical stations are hallway locations near nursing units, kitchens, pharmacies, sterile supply rooms, etc. Hallways are typically 6 to 8 feet wide: wide enough for the HelpMate to navigate around an obstacle and continue on its way. Hallways on the patient floors are typically cluttered with wheel chairs, beds, maintenance carts, etc. In addition, the hallways must be shared with the hospital staff, patients, and visitors. The HelpMate makes use of an elevator to travel from floor to floor.

The HelpMate requires fewer modifications to the environment than would a traditional AGV. No buried wires or painted stripes need be installed for navigation guidance. In a relatively long hallway, a strip of retro-reflective tape may be mounted on the ceiling from wall to wall in order to mark a distance along the hallway. A TRC-developed elevator interface system allows the HelpMate to use a radio link to control an elevator as though it was manually (i.e. physically) operating the elevator. The elevator interface system also provides elevator status such as which floor it is

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on, whether its moving, door open or closed, etc. In a hospital the HelpMate may have to pass through a door that, as a matter of hospital policy, remains closed. In these cases a door opener with an infra-red link is installed to allow the HelpMate to open and close the door as needed. At some stations the personnel cannot see the HelpMate when it is waiting there. An "annunciator" can be installed that is turned on and off by the HelpMate to indicate when it is at the station. The annunciator chimes and lights up when activated.

When the HelpMate is performing a specific transportation task it is said to be on a mission. The current types of missions that the HelpMate can perform are:

(1) Round trip: the HelpMate proceeds through a specified sequence of stations and then returns to the starting station.

(2) One way trip: the HelpMate proceeds to the single specified station.

(3) One way trip with stops: the HelpMate proceeds through a specified sequence of stations.

(4) Rounds: the HelpMate proceeds through a pre-programmed sequence of stations.

These missions can be invoked with either of two methods: (a) the hospital staff can dispatch the HelpMate through its console interface or (b) an on-board, real-time clock can initiate pre-programmed missions as "Time-of-Day" (TOD) events. An application engineer consults with the staff to determine and program the rounds and TOD events. For example, the HelpMate could be programmed to perform a 3:00 pm diet change round as a TOD event. The round might consist of visiting several stations to collect diet change slips. If it is not on a mission at 3:00 pm the TOD event will trigger and the HelpMate will initiate the round on its own.

Information about a hospital's topology and geometry is provided to the HelpMate by means of a commercial CAD system and TRC-developed CAD-data processing software. A TRC application engineer discusses with a hospital which locations the HelpMate will travel to, which elevator(s) to use, door openers, annunciators, etc. The engineer determines the connectivity and measures the length and width of the hallways that the robot will navigate. All of this information is encoded in a CAD drawing and then written to a computer file in a standard CAD data format. This CAD data is processed by a TRC computer program to produce a "Topography Knowledge Base" (TKB) file which is downloaded to a HelpMate.

III. HelpMate Navigation Amongst People

The fundamental functionality of the HelpMate navigation is "hallway navigation". It is accomplished with the operation of four concurrent modules: dead-reckoning, registration, path following, and obstacle avoidance. The HelpMate's position and orientation is estimated by integrating the drive wheel velocities in the process of dead-reckoning. Registration is the process of estimating on-line the robot's position and orientation in the hallway through the use of on-board sensors to detect environment landmarks. As dead-reckoning errors continually increase, registration is used to update the position and orientation estimation whenever possible.

The HelpMate is able to follow a "desired" straight line path parallel to the walls of a hallway. In a repetitive process, the estimated position and orientation is used to generate an intermediate target point on the desired path. The intermediate target is used to calculate motion commands that servo the robot to the target. As the target points are generated so as to progress along the desired path, the robot tracks along the path.

An obstacle avoidance module operates in conjunction with the path follow module. It collects on-board sensor information and builds a local, robot-centered map of the area. When following the desired path would result in colliding with an object in the map, the avoidance module determines an overriding intermediate target point that can be reached without a collision. Motion commands are calculated to reach this intermediate target. These target points are generated such that the robot avoids an obstacle and then continues along its desired path. Unless a hallway is blocked, the HelpMate will reach the end of the hallway.

The HelpMate transitions from one hallway to another by switching from following one desired straight line path to another. Two forms of transitioning are used, a "zero-radius turn" or a "radius-turn". A zero-radius turn is performed by coming to a stop at the end of one path, turning in place to align with the next path, and then following along this next path. A radius-turn is performed by switching to the next path when the robot is some distance (e.g. 1 meter) before the end of the current path. The path follow algorithm achieves a smooth transition.

TRC has observed that hospital staff, patients, and visitors enjoy playing with the robot. An example is "being an obstacle" and watching the HelpMate maneuver around them. To increase the HelpMate performance by discouraging this playing, the robot's navigation behavior has been programmed such that it pauses for a few seconds before leaving the desired path and avoiding an obstacle. By not reacting to an obstacle so quickly the HelpMate is not as entertaining.

As the State of Connecticut requires that the public cannot ride in an elevator with the robot, TRC has adopted this policy for all of its installations. A sign indicating this policy and a flashing light are mounted inside all elevators used by the robot. To further ensure that no one rides with the robot the following behavior has been implemented. When it needs to use the elevator the robot puts it in a "priority mode": a mode such that the elevator will not respond to calls from the elevator lobbies. If people are in the elevator and have pushed floor buttons the elevator will

proceed to these floors. Eventually, there will be no more passengers and the elevator will sit with its door closed, not responding to external calls. The robot tests for this empty condition by requiring that the elevator is not moving with its door closed for a specific period of time. When the elevator is empty the robot moves forward to just in front of the elevator door to produce a "block" position. Only then does it call the elevator to its floor, board it, and continue with its mission.

More detail concerning HelpMate navigation can be found in [3] and work on navigation in an unstructured environment is presented in [4].

IV. The HelpMate User Interface

The HelpMate's user interface has three components: (a) HelpMate startup, (b) user dispatch and receipt of payload, and (c) status and control during navigation. In designing the user interface it was important to recognize that the hospital staff using the HelpMate (nurses, kitchen workers, pharmacists, etc.) typically does not have experience programming computers or industrial robots. An interface that an engineer finds user-friendly, the hospital staff may not.

Figure 1 provides a sketch of the HelpMate with its main components labeled. The HelpMate has sonar and structured light range sensors which provide information for obstacle detection and registration. A bumper that surrounds the base of the HelpMate has upward looking sonars to detect close proximity obstacles. The bumper also has switches to detect physical contact with it. A rechargeable battery pack is removable to allow the robot to operate almost continuously. A back pack can have multiple compartments to hold the payload that the robot transports. The HelpMate can be equipped with a number of different types of back packs and both the back packs and the battery packs can be changed by a single user without any lifting. Back pack and battery pack carts are provided; a pack is simply slid onto the cart and wheeled away and the new pack is slid into the HelpMate.

The warning light and turn signals are indicated as well as the emergency stop switches. The robot has handles for manual operation. A thumbswitch is used to control the robot's speed when moved manually. Finally, the console is shown at the top of the HelpMate. Figure 2 shows a detailed view of it. A backlit LC display is used to display written messages. (Not shown is the speech system for audible messages.) A keypad allows a user to select menu options or enter values. The <PAUSE> button is provided on the console just above the power switch.

A. HelpMate Startup

When the HelpMate is powered up the process referred to as "power-up diagnostics" is invoked. Its purpose is to test the robot for proper operation. Only if the robot passes all of the diagnostic tests will it enter into operation and allow itself to be dispatched on missions. The staff member that starts up the HelpMate at the beginning of a shift or after a battery back change needs only turn on the HelpMate to initiate the diagnostic tests. TRC does not provide customers with a means for circumventing the power-up diagnostics procedure. At the start of power-up diagnostics the robot display requests that the HelpMate be positioned facing a wall. The wall should be lightly-colored and slightly-textured, and the robot should be positioned about 1 meter from the wall. The robot will rotate in place and move to and from the wall while performing the diagnostics procedure and so a sufficiently large, obstacle-free area should be provided. The user should stay clear of the robot so as not to interfere with the tests of its sensors. The power-up diagnostics procedure consists of a series of tests and as each test is run, its name is displayed. If a test fails, the procedure stops and the error is reported. Any error prevents the robot from being dispatched.

B. User Dispatch and Receipt of Payload

Currently, a user may dispatch the HelpMate on a mission and receive a delivered payload through the use of the robot console display and keypad. The robot provides a simple menu system making use of the display and the numeric keypad. On the top-level dispatch menu, the types of missions (round trip, oneway stop, etc.) are displayed for the user to select. Subsequently, a different menu is displayed for each type of mission. For example, for a round trip mission, the user selects for each backpack compartment the desired stations. At any point the user can return to the top-level menu with the "Cancel" selection or start the mission with the "Go" selection. When the robot arrives at a station, it displays a message instructing the user to examine the appropriate compartment and to press the <ENTER> button to continue with the mission. The HelpMate will wait a specified amount of time at a station before giving up and continuing with its mission. While waiting at a station it beeps periodically to call attention to itself.

C. Status and Control During Navigation

While the HelpMate is navigating to a station, it provides several means for interacting with the hospital staff and visitors. A flashing light on top of the robot indicates that is navigating (as opposed to waiting at a station). Left and right flashing lights are used to indicate the direction of a turning maneuver. Flashing both left and right lights is used to indicate an obstacle avoidance maneuver. Prerecorded voice messages are spoken to announce conditions such as "my way is blocked, please move the obstacle", or "I have

completed my mission". The console display indicates the robot's current mission and its current destination.

Occasionally, a patient emergency requires that a hallway be cleared quickly to allow patient transport. As HelpMate does not respond to spoken commands two manual methods are provided for interrupting his current mission: (a) emergency stop and (b) pause. Emergency stop buttons are easily accessible and mechanically disconnect power to the drive motors. For safety, the HelpMate cannot override an emergency stop button. When an E-stop button has been pushed the robot can be moved manually as it will roll freely. The robot will announce every 15 seconds "my emergency button has been pressed, please call the operator". If the button is pulled up, the display instructs the user to press the green keypad button, <ENTER>. When pressed, the robot will pause for a few seconds and then continue on its mission. The preferred method for temporarily pausing and/or moving the HelpMate is to use the <PAUSE> button. When this button has been pressed the robot decelerates smoothly and allows itself to be moved manually using the handle thumbswitch for speed control. When <PAUSE> has been pushed and the robot is stationary (not being moved by a user), the robot will delay for a specified period of time and then continue on its mission.

V. HelpMate Performance

The HelpMate logs information consisting of the number of times it has been dispatched to a station and the number of times that it arrives at a station. When a mission is not completed the reason is logged (e.g. emergency stop button pushed, etc.). The success rate of the HelpMate is about 98%. However, many failures are known to be due to user error (e.g. starting the robot at an incorrect location), elevator inoperation, an emergency stop button pressed, etc., and not due to HelpMate hardware failure or insufficient navigation capability.

VI. Future Developments

Currently the HelpMate can only be dispatched on a mission by a user through its console interface. Often a user needs to send the robot on a mission to pick up and return with an item but the robot is waiting for a mission at another station. We are currently developing a telephone interface for remote monitoring and dispatch. A user will be able to call up the telephone interface system and request that a HelpMate proceed on a specific mission.

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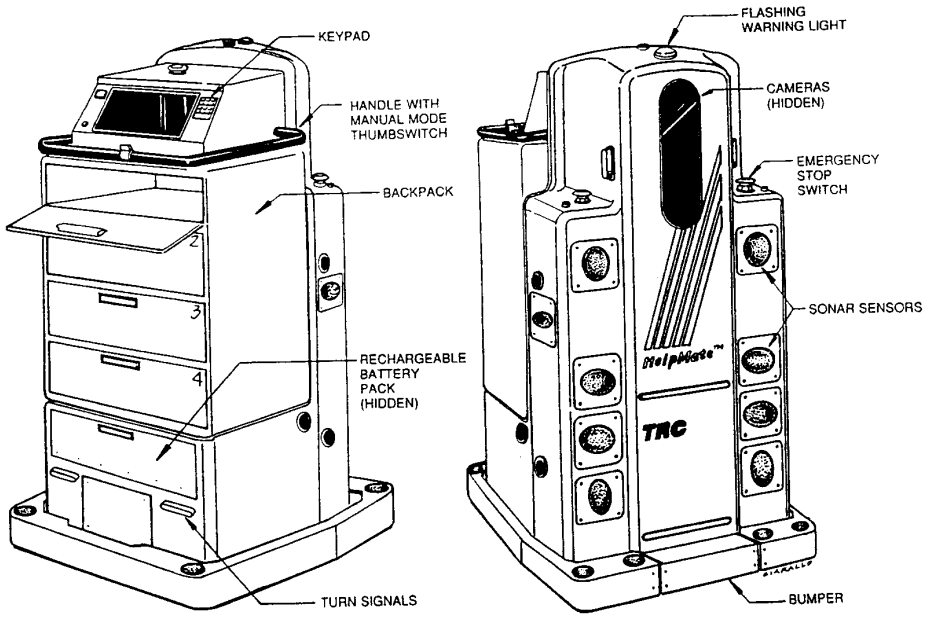

Figure 1: The HelpMate sensor and user interface components.

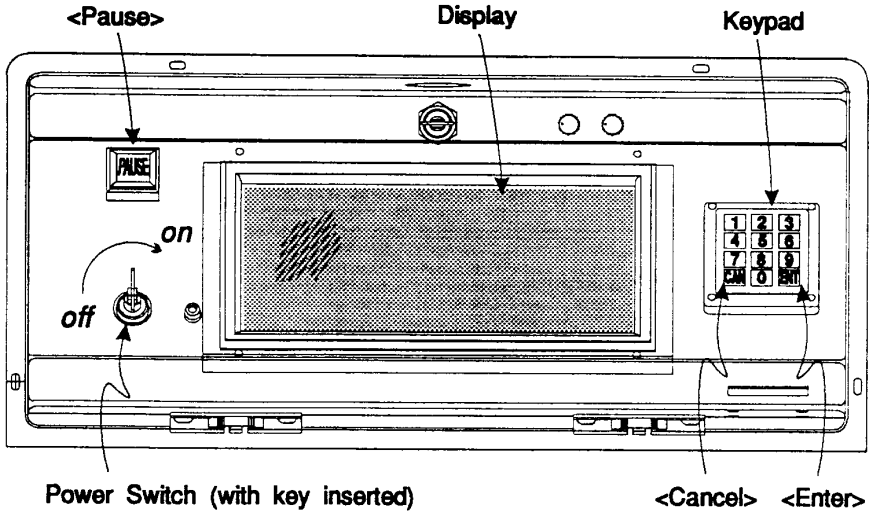

Figure 2: The HelpMate console.