

AUTOMATIC NURSING SYSTEM WITH STATIONARY SENSORS AND MOBILE ROBOTIC PLATFORM

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ABSTRACT

This paper presents the concept, structural design and implementation of components of a multifunctional sensory network, consisting of a Mobile Robotic Platform (MRP) and stationary multifunctional sensors, which are wirelessly communicating with the MRP. Each section provides the review of the principles of operation and the network components' practical implementation. The analysis is focused on the structure of the robotic platform, sensory network and electronics and on the methods of the environment monitoring and data processing algorithms that provide maximal reliability, flexibility and stable operability of the system. The main aim of this project is the development of the Robotic Nurse (RN)—a 24/7 robotic helper for the hospital nurse personnel. To support long-lasting autonomic operation of the platform, all mechanical, electronic and photonic components were designed to provide minimal weight, size and power consumption, while still providing high operational efficiency, accuracy of measurements and adequateness of the sensor response. The stationary sensors serve as the remote “eyes, ears and noses” of the main MRP. After data acquisition, processing and analyzing, the robot activates the mobile platform or specific sensors and cameras. The cross-use of data received from sensors of different types provides high reliability of the system. The key RN capabilities are simultaneous monitoring of physical conditions of a large number of patients and alarming in case of an emergency. The robotic platform Nav-2 exploits innovative principles of any-direction motion with Omni-wheels, navigation and environment analysis. It includes an innovative mini-laser, the absorption spectrum analyzer and a portable, extremely high signal-

to-noise ratio spectrometer with two-dimensional detector array.

Keywords: multi-functional sensor; spectroscopic sensor; robotic nurse; sensory network; Omni-wheel robotic platform

INTRODUCTION

Problems and Trends:

This paper presents the concept and practical implementation of some components of a sensory network that includes a multifunctional scientific instrument located on a mobile robot and those incorporated in multiple stationary units. The main task of the network is to take some of the more tedious responsibilities from a human nurse and to monitor simultaneously a large number of patients located in different places. It is referred to here as a Robotic Nurse Network (RNN).

The problems and solutions discussed in this paper can be grouped in five categories:

1. Robotic movable platforms.
2. Network of robots, instruments and humans.
3. Sensors and instruments.
4. Electronics.
5. Algorithms and software.

Multifunctional Systems:

An extremely important characteristic of a robotic platform with multifunctional sensors and instruments on-board is reliability. The simple duplication of the same elements (e.g., sensors, engines, cameras) is not appropriate in this case, since this will result in an increase of power consumption without receiving new information or capabilities. To solve this, multifunctionality of each element helps to minimize power losses, but still receives new information or supports more actions. The question is how to build a system of highly reliable switchers that provide transmittance of different signals to the robot processor and return back the command to specific motors, lasers and other devices through the same or a

minimal number of wires at a maximal rate. Probably the most effective way is to use multi-channel parallel wireless communications inside the robot system, the same as is used for outside communication. Such architecture gives a second advantage to the robotic platform: synchronous operation of two or more robots. Two “synchronized” Robotic Nurses can transport a patient without difficulties. The next idea proposed in this paper is to distribute the presence of the robot over a large number of patients or over a large monitored area by use of multiple stationary sensory nodes. In this case, RN permanently monitors hundreds of patients and moves in the area where its presence is the most necessary.

General Requirements:

The main goal of our work is to design a real helper for operation in a hospital or home environment that can use a distributed network of stationary multisensory nodes. The mobile platform is capable of serving as a Robotic Nurse, hospital security guard, home babysitter or a senior’s helper. The RN should:

1. Monitor general environmental conditions for security purposes;
2. Remotely monitor patient temperature, pulse and breath intensity and content;
3. Deliver scheduled medication;
4. Carry medical instrumentation, such as a vein visualizer, defibrillator, emergency medications in a pen syringe, etc.;
5. Be capable of self-charging from any electrical outlet in the hospital building;
6. Communicate with doctors, the nursing station, hospital administration, security guards, patient’s relatives, etc.;
7. Could be easily integrated into the Robotic Nurse network;
8. Must be easily upgradable;
9. Supply environmental, medical and security data in formats compatible with current standards, already existing systems, networks or medical instruments;
10. Must be fabricated with the materials and use techniques that are allowed in healthcare areas.

FROM HUMAN BEINGS TO ROBOTS

The wheeled systems are the most economical, fast, and have minimal operational noise and are easily repairable. The question is how to provide the maximal maneuverability and stability of the

system. Specific Requirements to be used in the role of RN, the robot should have certain properties. First, it should be able to move in enclosed environments, recognize possible obstacles, identify personnel and recognize patients who need to be served. In order to achieve these goals, it is clear that the robot should have the capability to climb stairs and go over doorsteps. At the same time, the robotic means of interaction with a patient should be on such a level that it should be able to interact with patients lying on the floor, standing up and lying in bed. It should be strong enough to provide support to the patient in some cases, such as moving from the bed to the chair. It also should serve the patient’s medicine at the proper time and help with other physiological activities. It has to be stable enough so that it cannot be easily tipped over. In the case that it is tipped over, the RN should be able to re-establish its standing position. The RN should contain some storage space in which medicine, utensils and food trays can be stored and brought to the patient.

To move without collisions and estimating well the safe way of moving within a populated area, the profile and sensing system should respond to several requirements:

- (1) the robot “body” should be column-like: relatively smooth and with a narrow profile;
- (2) to move stably, it must have a low centre of gravity and a relatively large pedestal;
- (3) to see “over a crowd”, it must have a camera tower of changeable height and angle of viewing;
- (4) to estimate the scene adequately, the distance to obstacles and to find the optimal route, the robot should possess a stereo-camera and range finders;
- (5) the screen position should be slightly higher than the head of a patient in bed;
- (6) it is preferable that the cameras operate in different spectral ranges;
- (7) The robot must navigate and move autonomously without the close presence of hospital personnel.

All these criteria were used to design the Robotic Nurse movable platform shown in Figure 1 [12]. The system of the “communicating” robot version is very lightweight and is easily transportable to any necessary location.

The RN is located on the compact movable platform, Nav-2, using three Omni-directional wheels (Figure

2). The Nav-2 platform is able to move in any planar direction. It is controlled over the in-office IEEE 802.11 wireless network.



Figure 1. The Robotic Nurse modular prototypes. A robot without the cover demonstrates a movable platform system.

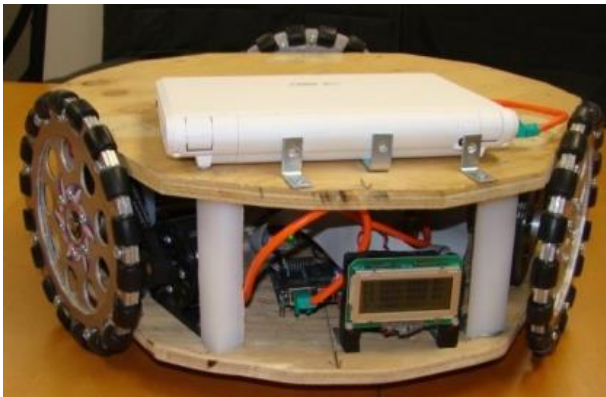


Figure 2. Three-omni-wheel movable platform.

Arms/Hands(Manipulators):

When RN provides some near-patient delivery or diagnostic actions, the stability and repeatability of the arm motions are extremely important. In practice, the robotic manipulators present some degree of unwanted vibrations. The advent of lightweight arm manipulators, mainly in the aerospace industry, where weight is an important issue, leads to the problem of intense vibrations [20]. On the other hand, robots interacting with the environment often generate impacts that propagate through the mechanical structure and produce vibrations, also. In order to analyze these phenomena, a robot signal acquisition system was developed. The instrumentation system acquires signals from several sensors that capture the joint positions, mass accelerations, forces and moments and electrical currents in the motors.

The application fields of robot arms are now extended well beyond their traditional use. These fields include

physical interactions with humans (e.g., robot toys) and even emotional support (e.g., medical and elderly services).

Rangefinders:

In our project, we partially used the proposed technology through acquisition of the visual information achieved from the stationary node. For estimation of scene changes, the information achieved from cameras, optical and ultrasound rangefinders of the stationary node and the movable RN will be used.

The two-level navigation system is designed to support reliable robot operation in complicated indoor conditions of the concrete/steel wall buildings (Figure 3). The near-field navigation is supported with optical and ultrasonic rangefinders. Infrared sensors point in six directions at the ground and can be used as cliff sensors or to remotely detect obstacles. The sensors are positioned 0.5 m above the ground and point at the ground 0.5 m away from the robot.



Figure 3. Robotic Nurse navigation ports: 1—infrared cliff/obstacle sensor, 2—ultrasonic sensor.

Cameras:

Currently, the robot is supplied with two different types of cameras: 360°-panoramic viewing and narrow-angle viewing. In Figure 4, one of the RN versions is shown: The panoramic camera is installed in the bottom part of the robot body and looks up on the spherical reflector that provides panoramic viewing. The next version of the RN will have a panoramic viewer located on the telescopic tower over the monitor.



Figure 4. Robotic Nurse top devices: 1—360°-panoramic viewing; 2—stereo pair; 3—speaker.

This tower will include the IR camera for night vision and temperature monitoring purposes. Additionally, a stereo-pair camera is installed on the upper pipe-frame that is supposed to protect the monitor in case the robot falls down. Besides a panoramic camera, all other ones will be equipped with zooming, scanning and targeting options. To remotely measure patient temperature, the infrared camera will be used.

NEXT STEP REVOLUTION

This paper describes the first basic robotic platform aimed at completing the nurse's functions. However, CrossWing has already started conceptual design of the next more advanced version of the Robotic Nurse—“Medical Technician” robot (see photo in Figure 5). This robotic platform will be supplied with different diagnostic tools: ultrasound, X-ray, optical and THz devices. It is being designed to operate with a non-linear microscope, coherent tomography, laser-ultrasound scanner and polarimeter. In all these technologies, we plan to use the fiber laser-based system. Such fiber devices ideally match the requirements to operate within robotic arms, to be immune to mechanical vibrations and to be the most effective, low-power consumption systems. The robot will accumulate all capabilities of the initial “communicator/sensor” RN version with additional options of a mobile diagnostic lab and medical technician.

Face Recognition:

A facial recognition system is a computer application for automatically identifying a person from a digital image [33–35]. Typically, it works by comparing some facial features from the image and from a database. Several software packages include face recognition option, such as Picasa, Picture Motion Browser, OpenBR, Windows Live, *etc.* Face recognition is not perfect; it works well with full frontal faces and angles up to 20 degrees off. In addition, other conditions where face recognition does not work well include poor lighting, sunglasses, long hair or other objects partially covering the subject's face and low-resolution images.

The detailed analysis of the technical and computational problems and their solutions for face and scene recognition is outside the scope of this paper. The most recent information can be found in three cited books [13–15] and in the International Journal of Advanced Robotic Systems.



Figure 5. The Robotic Nurse “medical technician” version will be supplied with different diagnostic instruments: X-ray, ultrasound, optical and THz devices.

DISTRIBUTED ROBOTIC NURSE

General Structure of the Robotic Nurse Network:

Besides the robot advantages described in Section 3, the most significant one may be that a single robot can be present in any point of the hospital, communicating with remote sensors through the telecommunication network. To minimize the cost of the system, to increase mobility, reliability and accuracy, the mobile robot with additional multiple stationary “eyes, ears and nose” has been proposed. These “organs of sensing” are boxed into special units: stationary nodes that are installed in different

hospital locations and are the elements of the hospital monitoring network (security functions) and patient conditions (healthcare functions). The structure and internal organization of this system follows the principles of a two-level network.

Homogeneous Sensory Network :

The proposed RN Network is a similar, but “inverse”, system to the classical cell-phone network. The difference is that in a cell-phone system, the central station is the high-power unmovable tower and cell phones are movable low-power units, all communicating with the tower. In the Nurse Robotic Network, the central station (robot) is movable and the nodes (analogy of cell phones) are unmovable (Figure 6). The nodes can communicate through the robot or directly between them. Besides the communication functions, the robotic network collects information about environment and patients, analyses the data and transmits them to the doctor or to the nurse station. Being based on this data analysis, the robot can make a decision and provide some actions: raise alarm, move to the critical patient and send message through paging, telephone, local security and/or internet systems. Such a network provides unprecedented capability of simultaneous and permanent monitoring of a large number of patients located in different places. A very important function of the network is to support communication through the stationary sensory nodes (for example, in hospitals or other multi-floor concrete-metal buildings). Such a system provides guaranteed robot wireless connection and control. An innovative system of robot navigation is based on a combination of information achieved from optical rangefinders (near-field) and radio signals from stationary sensory nodes (far-field). At the same time, a nurse station plays the role of data accumulation and storage server.

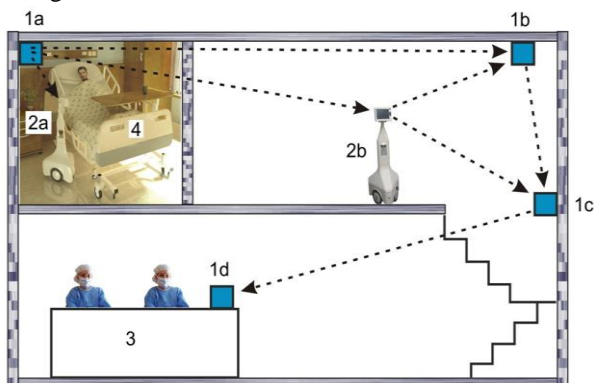


Figure 6. Diagram of the Robotic Nurse sensory network. 1a–1d—stationary sensory nodes; 2a, 2b—movable robots; 3—nurse station; 4—patient room.

The stationary nodes are used for robot in-hospital navigation by triangulation of the signals from several nodes. In total, the sensory node contains:

- (1) telecom unit;
- (2) multi-gas sensor unit;
- (3) environmental parameters sensors unit;
- (4) visible and IR-camera unit;
- (5) data processing unit;
- (6) radio/sound alarm devices.

The identical set of instruments is located on the movable platform. However, stationary nodes can contain more sensors and can operate at a higher rate.

Electronics:

One of the “hottest” problems of the robotic sensory platform is developing low-power, economical, but fast, electronics. The human organism does not use high voltage or high current processes to operate the body or to support the thinking process. One of the most sophisticated capabilities of humans is finding probabilistic solutions based on a limited volume of information. The computer solves the same problem by trying all possible variants. To achieve high efficiency of the operation, several ways can be proposed:

- (1) high computational rate computer;
- (2) minimization of number of the interface elements—development of the “through-the-system” electronics and operational software;
- (3) appropriate switching of the hardware elements to provide some functions in a parallel way;
- (4) multi-functional operation of the hardware and software.

Currently existing computers already provide the “Energy Star” mode of operation [96], with immediate “sleeping” mode when CPU activity is not necessary. At the moment of data acquisition and processing, the on-board computer should demonstrate maximal computational speed with relatively high-power consumption. At these moments, all unnecessary actions should be stopped. In other words, when possible, the RN will either walk or think and not both functions together. In the case of a fire or chemical alarm, the rate of the atmospheric gas monitoring will be a few measurements per minute; in regular patrol mode, just one measurement per several minutes. The most sophisticated part of RN behavior algorithms is to develop the priority levels for the robot action depending on the changeable environmental conditions. The question is: what to do first if the robot received a signal that one of the patients has a

heart attack and, at this moment, somewhere in hospital a fire starts? Such events are not a regular occurrence; however, the most tragic manmade catastrophes every time happen as a result of the coincidence of events of extremely low probability.

We already noted that a successfully operated robotic platform cannot be just a combination of separate well-known technologies. The general “skeleton” of the hardware and software should be developed from “zero”. Each junction should be designed keeping in mind some other connections, processes or technologies. An example of such electronic architecture is described in [9]. This paper reviews the direct connection of sensors to microcontrollers without using any analogue circuit (such as an amplifier or analogue-to-digital converter) in the signal path, thus resulting in a low-cost, lower-power sensor electronic interface. It discusses how resistive and capacitive sensors with different topologies (*i.e.*, single, differential and bridge type) can be directly connected to a microcontroller to build the so-called direct interface circuit. It then shows some applications of the proposed circuits using commercial devices and discusses their performance. Finally, it deals with the power consumption and proposes some design guidelines to reduce the current consumption of such circuits in activemode.

One of the strategic lines of the RN design is to develop a system that uses the same hardware element to complete different functions. For example, the tunable laser will be used for gas detection and concentration measurement, for range finding, as the excitation source for Raman spectrometer, for estimation of the atmosphere transparency and for some calibration purposes. To complete these functions, in some cases, the laser radiation should be switched to another optical channel or partially re-directed in propagation or be split into several channels. It means that controllable optical switchers should be specially designed to operate in the robot elements. Such elements are available commercially [98]; however, to work not on the lab table, but within the robot mechanical elements, they should be adapted to the robotic platform conditions. No mechanical stresses, no thermal variations and no vibrations are acceptable. This example confirms once again that to develop the Robotic Nurse, the scientific-engineering team must include specialists in physics, chemistry, computer science, electronics, mechanics and properties of materials, robotics, biology, psychology and medicine.

This paper is expected to be published in the Journal of Low Power Electronics and Applications. It describes the Robotic Nurse Network with a large number of different interacting devices. The electronics for RNN as a joint “nervous” system is not yet developed. This paper is an invitation for electronics specialists to join our team on the way to the creation of a smart medical robot.

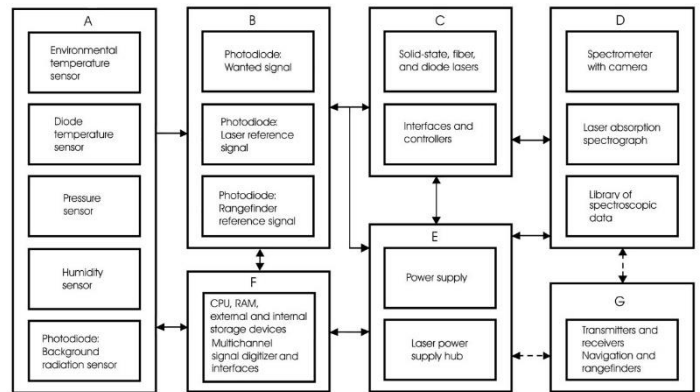


Figure 7. Block-diagram of the sensory system

CONCLUSION

This paper presents a review of research and practical implementation of the robotic systems capable of working in healthcare and housekeeping services. The conceptual, scientific, engineering, computational and psychological problems were analyzed on the ways of creation of the robotic nurse helper. The paper describes the prototype of the Robotic Nurse Network that includes movable and stationary platforms to monitor a large hospital area and to provide some healthcare functions. In addition, the RNN is capable of performing security functions. The RNN accumulated several innovations in movable platform mechanics, robotics, laser technology, spectroscopy hardware, data acquisition and processing, in multifunctional sensory devices, in principles of navigation and communication network organization. In total, the system is based on the multi-functional instruments concept and can support different actions with the use of the same equipment. The Robotic Nurse is applicable or easily modifiable to be used in:

- (1) hospitals;
- (2) kindergartens, schools, colleges and universities;

- (3) private homes and public places;
- (4) banks, government buildings; railway stations, bus terminals and other populated areas.

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