Smart Hospital Ward Management System with mobile robot WARDBOT: An efficient management solution for hospital ward

DMHT Dasanayake[1], PS Gunasekara[2], SN Dabare[3], HD Wickramasinghe[4], KLKTD Sandharenu[5] and S Fernando[6] and JDPR Jayasekera[7]

[1 2 3 4 5 6] General Sir John Kotelawala Defence University, Sri Lanka.
[7] Chittagong Medical College
[#] Corresponding author; <hasithict@gmail.com>

Abstract— *The hospital ward system is one of the major section of the hospital. Various ward management systems are used by hospital staff in order to maintain the system. This paper presents a novel concept of,* ***Smart Hospital Ward Management System*** *(**SHWMS)** based on mobile robotic platform (**WARDBOT**) for a public hospital ward in Sri Lanka. The need of a smart system combined with an assisting robot for performing activities in the public hospital system is great importance for doctors, nurses, patients and other healthcare assistances due to excess work load and limited work force. The Aim of this research is to provide efficient and effective solution for the drawbacks of ward management, patient monitoring, interacting, drug distributing, specimen collecting and ward preparation processes with the help of **SHWMS** and **WARDBOT**.*

Keywords— smart hospital ward management system, mobile robot platform, drug distribution, patient monitoring, specimen collecting.

I. INTRODUCTION

Hospital ward system is a complex co-domain of hospital system. Involvement of doctors, nurses, other healthcare assistances fulfil the requirements of the patients in the hospital ward system. Interaction between further mentioned personals help to maintain the smooth run of the ward system.

Doctors' tasks also include making a diagnosis and treatment plans for the patients in the ward, taking history of newly admitted patients, requesting laboratory results or radiological findings, making discharge notes and prescribing medicine and taking responsibilities of medical students and interns. Therefore, more responsibilities of ward management are done by the nurses.

Nurses play a major role in the hospital ward. Their role can be summarized as a caretaker, client advocator, collaborator, communicator, health educator and as well as a researcher. The responsibility of a nurse as a caretaker is to improve the state of physical, emotional, social and spiritual wellbeing of the patient and to restore and promote the health status. As a collaborator, the nurse should collaborate with the patient, his/her family and other multidisciplinary health care teams to meet the health care needs of the patient. It is the role of the nurse to support the other health care professionals to identify the critical needs of the patient. Finally, as an educator and a researcher, a nurse has enormous duties within the hospital. (Basawanthappa,2009). Admission is a process in which an individual is entered into a health care agency for medical or surgical treatment and nursing care. There are two types of admission processes: inpatient and outpatient admission. In, inpatient admission a patient's length of stay in the ward is more than 24 hours and vice versa. Whether it is inpatient or outpatient the main purposes of patient admission is for treatment, investigation, illness prevention and health promotion. (Potter, P.A., & Perry, A.G.,2011. Nurses assist the patient to adapt to the hospital environment, initiate effective nurse - patient relationship, relieve the anxiety of the patient and the family, develop a data base for individualized care plan and build patient's trust towards the institution. Several documents have to be maintained by the nurses as part of their duty such as the admission book, Bead Head Ticket(BHT), temperature chart, observation chart, intake - output chart, Capillary Blood Sugar chart(CBS), treatment sheets, diagnostic cards, drug chart etc. These documents have a legal value. Therefore, it's necessary to maintain these within a hospital ward system. Medicine management and distribution is one of the key responsibilities of a ward nurse. There are protocols for storage of medicine, especially for narcotics and controlled substances. Under responsibilities of medication administration, nurses are legally responsible for the safe and accurate administration of medication, having sufficient drug knowledge to recognize and answer the patient's question, to confirm "six rights" of safe medication administration and follow "three checks". (Fry S., & Johnston, M.J. 2008). Patient monitoring is a very important duty in a ward. That duty is done by a nurse. Also, monitoring present conditions of patients like hygienic level, level of saline, level of urine etc. is to be done by a nurse. Vital sign monitoring is a procedure that takes signs of basic physiology including temperature, pulse, respiration and blood pressure. Purpose of the vital sign measuring is to assess patient's conditions, to

determine baseline value for future comparisons and to detect changes or abnormalities of the patient and to evaluate his/her recovery from illness. This should be done with care as this data is referred by the doctor for diagnostic purposes. Specimen collecting, labelling and transporting are some of the duties carried out by a nurse. Under specimen collecting, blood and urine collection is very common. Nurses collect blood for blood culture before administrating antibiotics. They collect blood to a clean bottle with an infusion broth. The best time for collecting blood for blood culture is when the patient is having fever spikes, chills/rigors. Ideally urine is sterile. Nurses advise the patients to collect urine early in the morning before administrating antibiotics and to refrain from passing urine until the specimens are collected. Sterile, dry, wide necked, leak proof containers are used for collecting urine. When transporting specimen, it should be properly labelled with the patient's name, BHT no, name of the specimen and the ward number. (Bavin C., Cole E., Hunter J., 2012).

A Sri Lankan health-care delivery review revealed that limited no. of qualified nurses exists in many hospitals and medical institutions. Due to poor working conditions like lack of resources, busy work environment, poor infrastructure, an inadequate salary, lesser exposure to technology, lack of specialized education and limited carrier reconnaissance are the reasons for poor quality of patient care (Badurakada & Colleen, 2010). Therefore, outcomes of the above-mentioned duties are not up to standard. Documentation process of the hospital ward system has many draw backs due to inefficient method of data entering and retrieving. Therefore, level of reliability of the process is poor. Overcrowded patients, stressed out workers, single data entering facility are the main reasons for this. Medicine management and distribution within the present hospital ward systems has its own cons due to poor documentation system and excess number of patients. Medical negligence can occur due to these reasons. (Landmark Case of Medical Negligence in Sri Lanka, 2002) because of that it's risky for patients' lives. (Landmark Case of Medical Negligence in Sri Lanka, 2002) Also in the sense of drug distribution, two nurses spend nearly one or one and half hours to distribute the necessary drugs (Badurakada & Colleen, 2010). Therefore, due to these kinds of working situations, nurses limit the patient caring time and interaction time (Badurakada & Colleen, 2010). That results in reduction of physical, mental and social health of the patients. In Sri Lanka, due to excess work load and limited resources nurses have to work under pressure in the patient monitoring process. Generally, 75-85 patients are available (Badurakada & Colleen, 2010)in a ward but only 5 or 6 nurses are assigned on duty shift (Badurakada & Colleen, 2010). Deficiency of proper equipment, unreliable methods of measuring vital signs and monitoring patient condition cause an avalanche influence in diagnosing diseases.

To find solutions for the above-mentioned drawbacks in the hospital ward system knowledge of robotics, computer science, mechatronics engineering and medicine were used. Concept of **Smart Hospital Ward Management System (SHWMS)** based on **mobile robotic platform (WARDBOT)** is implemented to increase the efficiency and reliability in the hospital ward system by implementing **smart database management system, drug distribution system, low cost non-contacting vital sign monitoring system, patient condition monitoring system, specimen collecting, labelling and transporting system, ward preparation and maintaining system**.

Throughout this research, **smart hospital ward management system and drug distribution system** are mainly discussed and other systems will be discussed in future researches.

II. LITERATURE SURVEY

Continuous development of computer science, mechatronics and robotics and the applications based on synchronization of these three fields have been widely expanded. Impact of robotics in military, space, manufacturing and health-care applications brought huge success due to reliability, durability and effectivity. Nowadays different types of robotic technologies are used based on these applications. The shortage of healthcare staff has been a massive problem over the past decades in the world. Hospitals are overcrowded with patients, lack of resources, huge responsibility on nurses and staff has been highlighted in developing countries like Sri Lanka.

Therefore researches, scientists and engineers search different solutions for this issue. Usage of robotics is one of the most successful approach. Development of the mobile robotics, researches have showed its success in the hospital environment. In 1985 Koren et al. (Johann & Yoram, 1985) described the mobile platform for a nursing robot. The iWARD (Mamun, Sharma, Hoque, & Szecsi, 2014) is a nursing robot. It is an intelligent system for patient monitoring, cleaning and delivering within a mobile platform. Care-o-bot (Hans, Graf, & Schraft) and Skillgent (Healthcare/Eldercare Robot based on Skilligent, 2017) are servicing robots which can be used for home and hospital environment. Care-o-bot and Skillgent (Healthcare/Eldercare Robot based on Skilligent, 2017) are not capable of interchanging their service units. They are manufactured with onboard features. Also, those robots can't communicate in the ward network or connect to the ward server. iWARD (Mamun, Sharma, Hoque, & Szecsi, 2014) robots have interchangeable service units but those units are separately controlled. These methods are not suitable for hospitals which

allocates a separate time for each separate task. This method is not cost effective in developing countries because each and every unit needs a separate control system and power supply. Also in that system, they use sensor belts for each and every patient in vital sign monitoring purpose. That is an impractical concept for patients who has serious injuries and problems. Therefore, mobile robot with non-contacting vital sign measuring system is important in practical usage. It affects the overhead cost because vital signs are not monitored continuously in a hospital ward system. Cao et al. (Cao, Fukunaga A, & Khang A, 1997) categorized different architectures in the cooperative, multi-robot domain. Attempts have also been taken to analytically determine the minimum information required for solving a task (Donald, 1995) and for automatic generation of robot teams (Parker, 1998). However most of these attempts have not succeed the issues of distributed collaborative behaviour and distribution of resources across robots. Presently, self-navigating mobile robots have been used in many hospital systems (Ambrose & Askew, 1995) (Hayes, Martinoli, & Goodman, 2002) (Monkman & Taylor, 1993) (Shieh, Hsieh, & Cheng, 2004) (Takahashi, Suzuki, Cinquegrani, Sorbello, & Pagello, 2009). But the problem is that there is no point of using self-navigating robots for a properly mapped location. Therefore, mechanism to avoid obstacles and stopping is enough for these applications. If not it will be a resource wasting and power consuming activity. If we consider that beds are stable and patients are static, magnetic track guiding method is more reliable and quick.

Hospital ward management system is an essential computer based system for a hospital ward system. Database management, wireless networking are the key features of this system. According to Paul Vegoda (1987), hospital Information management system as an integrated information system which helps to improve the patient care by uplifting the user's knowledge and uncertainty allowing rational decisions to be made for the information provided. With the help of different software that are integrated in order to capture data in specific sections, helps to handle the work flow of the daily routine of medical staff and it also helps to keep administrative and clinical data up to date (Garrido, Raymond, Ling and Wiesenthal, 2004). Computerized database is necessary because it is hard to maintain huge amounts of paper work, and there is no backup of those documents and access to information is difficult and consume fair amount of time when referring. (Adebayo A. ,2014). Therefore, we can see that the system integration is required to have a proper organized database of patients' details.

Providing IT tools to health care professionals will help their daily activities. Mostly doctors and nurses do not have easy access to patients' records when they work at "bedside" and information is mostly recorded on paper and subsequently transliterated on paper for further processing (E. Cosacia, G. Dodero, S. Virtuso, V. Gianuzzi, 2012). Paper recording has been an issue when it comes to sharing information, retrieving information and storing information. Manual paper documentation takes a lot of space and time for data processing. Therefore, importance of computer based database management system is highlighted. The hospital information system is the complete information processing and information storage subsystem of a hospital, whereby it is not just about computer systems and networks and the computer-based application systems that are installed on them. But it encompasses all the information of the hospital. (B. Premakumar, K. Kalpana, 2013). Hospital database management is a huge area as it fulfils the services of different departments and personnel of a hospital.

Drug distribution is a very important process in a hospital ward. Several researches were carried out for the areas of drug dispensing and drug distribution. Karat and Jackrit (Karat & Jackrit, 2014) proposed a system for drug distribution among hospital wards via automated guided vehicles but their proposed system didn't touch the area of drug distribution among patients and nurses. Evaluations of automatic drug dispensing systems were done by Fritzpatrick et al (Fitzpatrick, Cooke, Southall, Kauldhar, & Waters, 2005) and Chapuis et al (Claire Chapuis, et al., 2010). Sakine et al (Sakine & Abdulsamet, 2015) described a system but that was based on voice commands of the nurse. Drawbacks can occur in that system due to busy and noisy environment of the hospital ward. Therefore, accuracy of the voice command cannot be guaranteed in risky and populated situations.

III. SMART HOSPITAL WARD MANAGEMENT SYSTEM

Concept of SHWMS is based on database management system, Smart mobile application and wireless network. Requirement of database defers from person to person who works in a hospital. Receptionist of the hospital system needs to take information of the patient. Therefore, requirements of the receptionist can be considered as: login to database, register patient, view patient record, search for past records and edit patient records. After getting registered, a nurse will take care of the patient. Nurse also needs to access the database for several activities:login to database, view patient's records, search for records, assign patient to ward and assign a bed to patient and upload daily readings of patient's health.

After these, the doctor checks the patient and needs to: login to database, view patient's record, upload patient diagnosis summery, search for history records of patient and upload prescription

In order to full fill above requirements, a database have to be designed in a particular manner where all the patients' records are kept in an organized, easily updatable and searchable manner. For that, a database is designed using MySQL. In that different types of tables are made for gathering admission information, drug charts, treatment information, different health parameters and lab test
reports. The interconnection among tables is made through Patient's ID which is given by the system.

To communicate with MySQL database, A web based interface is designed and that includes each and every form that the hospital needs to keep records of. Forms are linked to the database from PHP. HTTP protocol allows to update and view the data from the database easily. Toaccess the database (by using HTTP protocol), tablet devices are given to each nurse and doctor in the ward with a login ID.

Privilege level is given to the system based on profession. As an example, prescription only can be updated by doctor and automatically updated drug chart can be viewed only by nurse. Tablets are supplied to wards and to communicate with the server there is a Local Area Network in the ward which allows communication among tablets, with the database server and with WARDBOT.

There are wireless access points fixed in the ward to give wireless connectivity to the devices to login to the server. Access points are connected to a switch which will enable the connection between server and the access points. When Someone needs to work with the web application he/she can just type the Server IP and get access but for someone without a IT literacy is an issue. Therefore, Domain Name System (DNS) is used to make URL access easy. Server IP is given a domain name (ex: xxxxx.com) by DNS and using that staff can access the web app. Tablet devices communicate with server through web application which got a back end written from PHP. To communicate with robot, Python program with PHP plugins were used. The ward server is connected to the Hospital webserver in the Hospital website. Therefore, Doctors get the access to see the patient records from remote access capability.

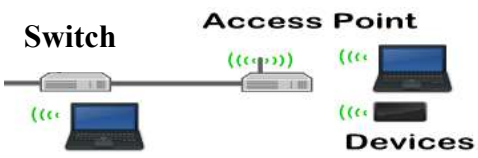

Figure 1. Web Interface example

To control the WARDBOT, nurses need to be signed in. then he/she can access the WARDBOT's controls such as drugs distribution, specimen collecting, ward preparation, patient monitoring. When a nurse is logged in to WARDBOT tab, he/she will get options to select the task. As an example, when he/she clicks on drug distribution, the search form will appear (which can be used to select

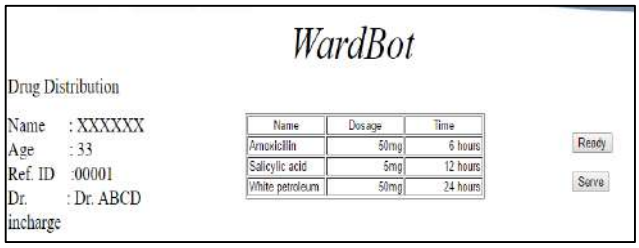

Figure 2. Network Architecture

the patient) the app shows the patient's medicine that has been prescribed by the doctor. Finally, the nurse has to give command to fetch the medicine.

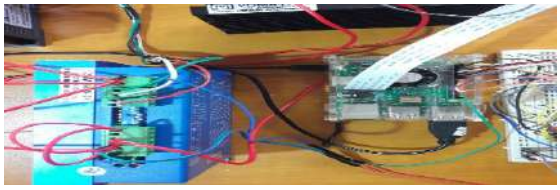

Figure 3.

IV. MOBILE ROBOT: WARDBOT

WARDBOT: Mobile robot design shows the importance of main robot unit and subordinate robot units for different applications. This design provides easy configuration, easy expansion, optimizable and economical solution for the hospital wards of developing countries.

WARDBOT comprises of no. of control units, each provides a distinct function, contributing to the overall task. The main robotic unit consists of a main control unit and a 6 degree of freedom robotic arm and it is controlled by an industrial computer with touch screen display and a Linux operating system. Along with it a secondary processing unit of single board computer "Raspberry Pi 3B" (R-Pi) is attached to do the processing for magnetic track guiding, obstacles detecting and avoiding for navigation. Other subordinate robot units for other applications can be connected automatically with the nurses' command.

A. Main Mobile Robot Unit: Mobile platform

Main mobile robot unit is the heart of **WARDBOT**. Magnetic track guiding method is used as the navigation method of the robot. A magnetic guide sensor detects and reports the position of a magnetic field on the horizontal axis, for the movement of robots on the ward floor. In the design, we used adhesive magnetic tape for the floor-level track which can be followed by the robot. Advanced signal processing accurately measures lateral distance from the track's centre, from a height up to 60mm. The magnetic guide sensor (MGS1600) of

"RoboteQ" (Building a Magnetic Track Guided AGV, 2013) provides a position resolution of 1mm. Compared to optical track guiding method, magnetic track guiding method is very reliable because hospital environments are full of dirt and with varying light conditions.

MGS1600 sensor has an inbuilt USB port. Therefore, it is capable of connecting with R-Pi. Then R-Pi processes it is using python and sends relevant commands to the motor controllers via CAN-bus protocol.

In here, 4 "Mecanum" wheels are used to drive the unit and to bear up the weight and for the ease of handling in connecting the main unit to the trolley (rather than using two-wheel drive with castor wheels). "Mecanum" drive is a type of holonomic drive base which can apply the force of the wheel at a 45° angle to the robot instead of on one of its axes. By applying the force at an angle to the robot, magnitude of the force vectors to gain translational control of the robot can be varied. In the sense of controlling "Mecanum" drive needs angle, magnitude and rotation.

V_x=The voltage multiplier for the x^{th} wheel
V_d=Desired robot speed $[-1,1]$
θ_d=Desired robot angle $[0,2\pi]$
V_θ=Desired speed for changing direction

$$V_x = V_d \sin(\theta_d + \frac{\pi}{4}) \pm V_\theta \quad (1)$$

Figure 4. Wheel Numbering

Four DC brushless geared motors were used with two "HBL2360" motor controllers (Brushless DC Motor Controllers : HBL2360, n.d.). These two dual channel controllers are connected with CAN-bus protocol to operate it as a single four-channel drive. One driver is served as a master and other as slave. Then master is controlled via R-Pi. MaxBotix USB ultrasonic sensors (MB7363) is used for the object detection and stopping purpose of the mobile robot. That is capable of connecting to the R-Pi through a USB port. Therefore true/false output from the sensor makes an easy processing in R-Pi.

Power for the mobile robot unit is given by a valve regulated lead-acid battery pack. Valve regulated lead acid batteries are ideal for hospital environments where cleanliness is important and gassing is not permitted. There is no watering or special equalized charging needed for the life of the battery under normal conditions. Automatic battery swap out charging method is used due to the busy hospital environment. This method allows the mobile robot to operate for about 12 hours and up to 5 to 10 minutes of down time for the battery replacement procedure. (AGV Kennis Instituut, n.d.)

B. Main Mobile Robot Unit: 6DOF Robotic Arm

Robotic arm consisted with waist, shoulder, elbow, wrist and end-effector. Six joints were named X, Y, Z and A, B, C. Separate six servo motors were used with harmonic drives and Mesa card to control the motion of the robotic arm. The Mesa card (7I96) is an ethernet connected motion control interface designed for interfacing step and direction of servo motor drives and TTL inputs and outputs of the system.

Robotic manipulator and the control system was designed but end-effector of the robotic arm was decided to use an industrially available one. 3-finger adaptive gripper of RobotiQ (3-Finger Adaptive Robot Gripper - Robotiq, n.d.) was selected for the whole research and for this research, end effector with camera and vacuum head was designed.

As an operating system customizability of Linux, can be considered as an optimum solution for this application. Special software called "Linux CNC" was used as the controlling application of the manipulator. According to "Linux CNC", there are main two types of file systems. INI and HAL. INI files are generally used by "Linux CNC" to store their individual settings. Hardware Abstraction Layer (HAL) files are type of files which allows a computer operating system to interact with hardware devices at a general or abstract level rather than at a detailed hardware level. The hardware abstraction layer can be called from either the operating system's kernel or from a device driver. Robotic manipulator was configured by referring to the INI and HAL files of "PUMA 560" (Puma560, n.d.). The kinematics is provided in LinuxCNC by a specially written component in the C language. This can be used in HAL file. Inverse kinematics is used in some applications of this research.

C. Subordinate Mobile Robot Unit: Drug Distribution

Subordinate units are used in this research to connect various service units to the main mobile robot unit. Drug distribution is one the major task in the hospital ward

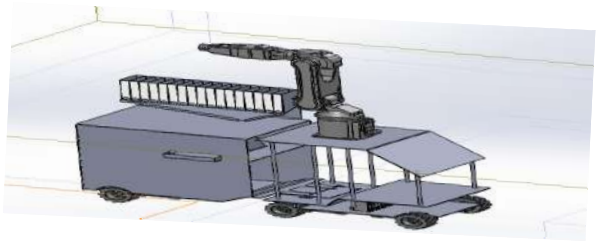

Figure 5. Robotic Arm with Drug Distribution unit

system. In this research, an effective method was implemented for that.

When a nurse wants to provide medicine for patients in a ward, she uses the given tab to command the robot to do the task. If the main unit in the robot is available for use,

it sends a signal back to the tab informing that it is getting ready for operation. After that the main unit connects the drug distribution unit to it and the combined unit goes from patient to patient with the nurse in order of patient number. This mechanism is navigated by track guiding and object avoiding mechanism.

By the patient ID, the PC of main unit accesses the ward database and retrieves data related to that particular patient. Then the medicine which was prescribed by the doctor is indicated by a LED in the relevant dispensers for the particular patient. Then nurse should confirm the medicine with the information given by the database using the tab. When the confirmed signal is received by the unit, it dispenses the tablets and capsules.

According to the nurses' responsibilities, nurses should follow "three checks" in medicine distribution. Our system is designed according to these regulations. Therefore, in our system 1st check is covered in medicine uploading (to containers) moment as 1st confirmation in the mobile application. Then 2nd check is covered in 2nd confirmation of the mobile application and 3rd check is covered in final confirmation.

If syrups are prescribed, the camera in the arm focuses on the rack of syrups, and then the syrup is picked by the arm. For this application inverse kinematics is used in the robotic arm. By using inverse kinematics joint angles can be generated with the help of co-ordinates. In this research, we used simple technique to identify relevant syrup according to prescription. According to the system all the syrups are numbered and given a QR code. That code is printed and pasted on the cap of the syrup bottle. Then those syrup bottles are placed in a rack. That rack locates in a permanent place and fixed position is given

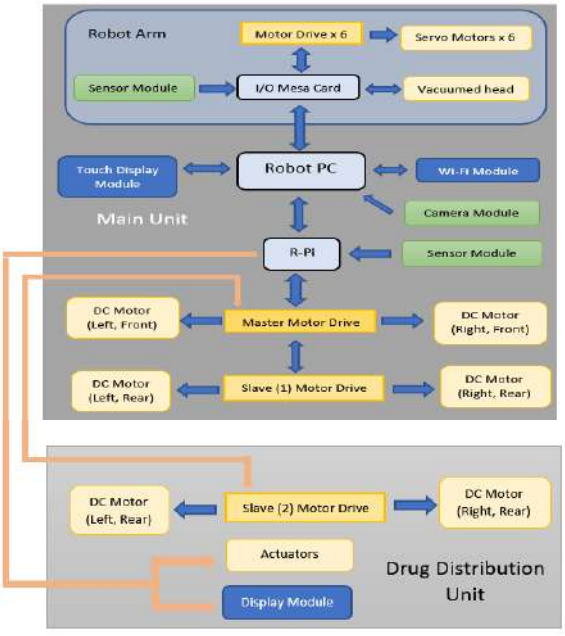

Figure 6. Main Structure

(above the rack) to the robotic arm to move when signal is given. Then it generates real co-ordinates with the help of laser triangulation sensor "MicroTrak 4". Finally picks the relevant syrup bottle.

For the above process, PHP-python plugin is used to crosslink PHP with python then OpenCV (OpenCV library, n.d.) library and QR code identification algorithms are used in python programming language to do the image processing and generate co-ordinates.

V. TEST, RESULT AND ANALYSIS

The testing of the SHWMS and WARDBOT were basically focused on hardware and software functionality.

A. *Smart Hospital Ward Management System*

Initially wireless network implementation was tested with the help of user interfaces of the system. Network simulation software called Cisco Packet Tracer [22] was used to check the accuracy of the network configuration. Then results were checked using the simulation tab. Collisions were not monitored therefore simulation became successful. Finally, network was built with the help of actual components and tested its' reliability and accuracy during the run time.

User interface was tested with the help of 30 users and their positive feedback was recorded as 83.3%.

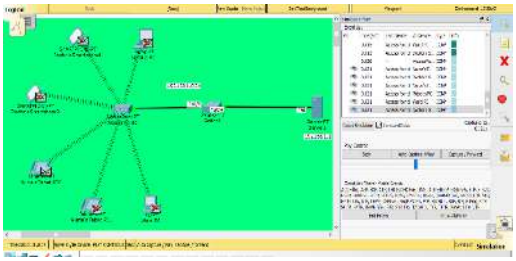

Figure 7. Packet Tracer Simulation and Web App Testing

B. *Mobile Robot: WARDBOT*

The main unit and subordinate units were separately tested through software simulation tools. Some models of mechanical structures were built in order to test.

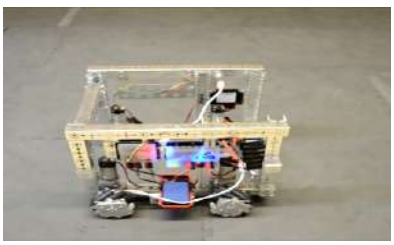

Figure 8. Physical Model Testing after V-Rep Simulation

Controllings of the units were simulated in V-Rep Pro Edu (Coppelia Robotics V-REP: Create. Compose. Simulate.

Any Robot., n.d.) based on Kuka youBot and animated it in Solidworks. Only the Mecanum wheel base structure was physically tested.

Finally, consumed time for the application was taken in order to do analysis.

C. *Discussion*

Table 1. Shifts

Shift	No. of Nurses	No. of (h)
Morning	7	6
Evening	5	6
Night	2	12

Table 2. Test Results

Action	Consumed time(s)
For patients	3771 (65X58)
Travelling	290
Total Time	4061

Each shift has a drug distribution process; consumed time for drug distribution is 90 minutes. Two nurses are allocated for the duty. No. of patients in the ward is 58 (Badurakada & Colleen, 2010)

Drug delivering time for patients in present system is 5400 seconds and drug delivering time for patients in automated system is 3771 seconds. Finally, total time difference is 1629sec (27 minutes). Time consumed for drug distribution for two nurses is 10,800 seconds and time consumed for automated system for one nurse is 3,771 seconds. Therefore, in automated system time of 90 minutes for one nurse and 27 minutes of another nurse can be cancelled. Finally, total gain of the system can be increased from 2 hours. Therefore, automated system is 65.08% efficient than manual system.

VI. Conclusion

This research proved the concept and implementation of reliable and efficient method for hospital ward. The overall system is also effective in terms of performance and cost due to multipurpose implementation and customizable feature.

VII. Acknowledgement

The authors would like to acknowledge Sir John Kotelawala Defence University and Chittagong Medical College Bangladesh.

VIII. References

Basawanthappa (2009) Nursing Education New Delhi, Jaypee Brothers.

Patrica A. Potter Anne & Griffin Perry, (2012), Fundamentals of Nursing, (11th Ed), New Delhi.

Fry S., &Johnston, M.J. (2008), Ethics in nursing practice (3rd Ed.), London, United Kingdom: Wiley.

Bavin C., Cole E., Hunter J., (2012), Essential Nursing Skills (4th Ed.), London, United Kingdom.

Ambrose, R., & Askew, R. (1995). An Experimental Investigation of Actuators for Space Robots. *IEEE International Conference on Robotics and*, 2625 – 2630.

Badurakada, S. S., & Colleen, R. (2010). Health-care system and nursing in Sri Lanka:. *Nursing and Health Sciences*, (pp. 33–38).

Building a Magnetic Track Guided AGV. (2013).

Cao,Y.Y., Fukunaga A, S., & Khang A, B. (1997). Cooperative. *Autonomous Robots, 4(1)*, 7-27.

Claire Chapuis, Roustit, M., Bal, G., Carole Schwebel, P. P., Sandra David-Tchouda, Foroni, L., Pierrick Bedouch. (2010). Automated drug dispensing system reduces medication errors in an intensive care setting. *Crit Care Med, 38*, 2275-2281.

Donald, B. R. (1995). Information invariants in robotics. *Artificial Intelligence, 72 (1–2)*, 217–304.

Fitzpatrick, R., Cooke, P., Southall, C., Kauldhar, K., & Waters, P. (2005). Evaluation of an automated dispensing system in a hospital pharmacy dispemsary. *The Pharmaceutical Journal, 274*, 763-765.

Hans, M., Graf, B., & Schraft, R. D. (n.d.). Robotic Home Assistant Care-O-bot.

Hayes, A., Martinoli, A., & Goodman, R. (2002). Distributed Odour Source Localization. *IEEE Sensors Journal, 2(3)*.

Healthcare/Eldercare Robot based on Skilligent. (2017, March). Retrieved from Skilligent:

Johann, B., & Yoram, K. (1985). A Mobile Platform for Nursing Robots. *IEEE Transactions On Industrial Electronics*, (pp. 158-165).

Karat, T., & Jackrit, S. (2014). A Study and Development on Robotic Drug Storaging and Dispensing System in Drug Logistics for A Mid-Sized Hospital.

Landmark Case of Medical Negligence in Sri Lanka. (2002). *Ceylon Medical Journal,*, 58.

Mamun, K. A., Sharma, A., Hoque, A. S., & Szecsi, T. (2014). Remote Patient Physical Condition Monitoring.

Monkman, G., & Taylor, R. (1993). Thermal Tactile Sensing. *IEEE Transactions on Robotics and Automation, 9*.

Parker, L. E. (1998). Toward the automated synthesis of cooperative. *Proceeding of the SPIE Mobile Robots XIII, 3525*, 82-93.

Sakine, Y., & Abdulsamet, H. (2015). DRUG DISTRIBUTION IN HOSPITALS REAL-TİME.

Shieh, M., Hsieh, J., & Cheng, C. (2004). Design of an intelligent hospital service robot and its applications. *IEEE International Conference on Systems, Man and Cybernetics, 5*, 4377- 4382.

Takahashi, M., Suzuki, T., Cinquegrani, F., Sorbello, R., & Pagello, E. (2009). A mobile robot for transport applications in hospital domain with safe human detection algorithm. *EEE International Conference on Robotics and Biomimetics (ROBIO)*, 1543-1548.