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Optimization and Dynamic Simulation of a Nurse Robot in Hospital Environment Using Genetic Algorithm

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Abstract

Optimization using results of dynamical and mechanical simulation of a robotic nurse unit to assist paraplegic patients, on a virtual path similar to actual hospital environment, is addressed in this paper. Force-Angle tipover stability margin measurement was employed in Genetic Algorithm optimization in order to find optimum driving and locomotion mechanism for the robot. By running the ADAMS® simulation of the robot on the path mentioned, Genetic Algorithm determines the wheels and robot center of mass locations for the optimum and tipover avoidant Nurse Robot Unit. 3D model simulation of the optimum locomotion mechanism solution, using Pro-ENGINEER® Wildfire®, and dynamic simulation of the results in ADAMS® software as well as experiments on the fabricated prototype proved the robustness of the robotic unit to tipover.

Keywords: Nurse Robot, Paraplegic, Genetic Algorithm, Optimization, Stability, Dynamic Simulation

1 Introduction

The goal of utilizing the robot as aids for regular and indoor tasks seemed to be man's first dream in the early days of robotics. In the period of eight decades after the first dream about robots, many robots were invented to work in specific indoor spots, such as houses, department stores and hospitals.

Because of having a vast population of spinal cord injured individuals in our country, it is clear that designing and prototyping a robot to serve in place of a nurse in treating duties while offering other services such as rehabilitation and physical therapy to paraplegic patients is essential. The nurse robot is designed such that it would satisfy most of a paraplegic patient needs in a compact unit [1].

Designing a balanced robot arm [2] or robot links optimization problem [3] using Genetic Algorithm (GA) were both experienced before. In this study, employing the GA in cooperation with dynamical simulation in order to obtain an optimum and tipover avoidant nurse robot unit is a novel work that is achieved using MATLAB® and ADAMS® softwares.

One of the most important dynamical effects in mobile manipulators is tipover. Unbalanced forces and inertias may lead the vehicle to instability and overturn. There has been a lot of work performed by researchers on the control of mobile manipulators and tracking problems including consideration of vehicle disturbances [4], [5] and [6]. Several methods for stability and tipover measure analysis are proposed up to this date. Huang et al. have investigated compensatory manipulator motion of mobile manipulators [7, 8, 9, 10]. In [7] three levels for deriving manipulator compensatory motion for stabilizing the whole system have been defined. In [8] stability against tipover is considered for path planning in mobile robots with known end effector's trajectory. In [9] feasibility of manipulator motion planning is studied. A similar method and approach is used in [10]. Huang et al. have used ZMP (Zero Moment Point) criterion as a tipover stability criterion [11, 12]. Then they used an iterative algorithm to find a proper manipulator motion, which impounds the mobile manipulator in a stable region. Their iterative algorithm is useful when the path of the mobile manipulator is known in advanced and can not be used in real time control of stabilizing the manipulator. In a relevant work, Rey et al. used a method [13] that is based on Force-Angle tipover stability margin measure. It uses the platform wheels, tracks or legs to compensate destabilizing moments exerted on the vehicle. Recently, Meghdari et al. [14] proposed a criterion based on upward wheel forces and used a Neural-Network as an observer to detect the distance from the stability margin. On the other hand it is not sufficient to prevent tipover and instability problem. Optimally mechanical robot mechanisms design guaranteed tipover and instability prevention due to external disturbances. In order to accomplish this, obtaining an appropriate tipover stability margin in design step, is very interesting problem in mechanical parametric optimization design.

Due to optimum mechanical design, for tipover avoidance, Force-Angle tipover stability margin measurement in Genetic Algorithm (GA) code using MATLAB ® software was employed. The GA using dynamical simulation results from the ADAMS® software for a path passed by the robot finds the optimum locations of the robot wheels and center of mass.

Studying 3D models of the optimum locomotion mechanism solution, using Pro-ENGINEER® Wildfire®, and dynamic simulation of the results by ADAMS software proved the tiopver avoidance of the robotic unit. (Figure 4)

2 A Robotic Nurse Unit to Assist Paraplegic Patients

According to Iran Welfare Organization statistical study, there are a big number of 84358 registered or non-registered spinal cord injured individuals in Iran. Experiencing other diseases and malfunctions in body organs, called secondary problems which mainly arise from immobilization, the paraplegics need nursing and rehabilitation processes that requires a high strength as a nurse and the capability of doing repetitious tasks that results in less desire for this duty in professionals in hospitals [15, 16, 1].

Studying paraplegic patients' needs, the best feasible design features which a nurse robot should achieve in service for paraplegic clients in hospital and sanitarium were determined; the most important duties for the robot are as below:

1. Patient's location and orientation identification.
2. Helping the paraplegic person to re-locate or move.
3. Finding a specific room and show the most efficient route through the hospital corridors.
4. Helping the paraplegic to stand by using a passive standing mechanism.
5. Rehabilitation and Physical therapy on knee and ankle joints.
6. Improving motion abilities of the paralyzed legs by exercises.
7. Following the medical team, as well as, patient orders through remote control.
8. Offering a video interface between client and physician.
9. Food and medicine delivery in hospital [1].

To satisfy the initial needs and tasks mentioned above, some of the mechanical and control features of the nurse robotic unit are:

Mobile platform: following orders remotely and having good maneuverability in hospital environment (serving as a wheeled chair and a walker).

Rehabilitation guidance: passive standing, knee bend and rest physical therapy, ankle joint physical therapy, tense pulse maker to relief muscles pain and improve joints situation.

Remotely controlled: complying with both patients and medical team orders a well as establishing remote video interfaces and online video monitoring.

Rounded cylindrical shape: the best obstacle avoidance while navigating between beds in rooms, and corridors, capability of direction changes, rotation and steering in a minimum space with maximum stability [1].

3 Mechanical Structure and Mechanisms Design

It is important to design the locomotion mechanism suitable for safe navigation in hospital environment. To obtain optimum design features for a desirable locomotion and steering mechanism, many solutions were reviewed, from which, some were assessed to perform the best base traveling system. It is to be said that some of the verified mechanisms were imitations from old and well-known drive and steering mechanisms such as car type steering [17], tracked locomotion and tricycle with rear wheel differential drive or synchronous motors [18]. Some other solutions were picked out from successful prototypes of recently prototyped mobile robots such as Omni-directional wheels [19]. In this project a new innovative design suggested and expected to behave better than traditional ones. With computer aided dynamical analysis, simulation was assessed to discover the characteristics of the plan by satisfying some parameters such as feasibility, reasonable weight, performing no harm to clinical environments and hygienic spots in it's workplace, using the least radius for U-turns or changing direction to the desired orientation without changing it's location, and demonstrating more stability and utmost tipover resistance. Taking advantage of utilizing Pro-ENGINEER® Wildfire® software as mechanical part simulation software in cooperation with ADAMS®12 software as a dynamical analysis and simulation software, a five wheeled mechanism, as shown in Figure 1, with two castor and three drive wheels placed on a circle perimeter, such that two of the drivers placed in the front, running the body forward with the aid of the third drive from the rear of the robot is suggested. By mounting mechanisms to revolve the runner wheels driver to orientate tangent to the circle, assumed for locating the wheels around it, and running the drivers motor in same direction, the robot will rotate on-spot around an imaginary axis normal to ground plain and passing through the mentioned imagined circle. For using the robot as a carrying wheeled chair while trying to use an optimum space for controllers and actuators employed for every task, a box-like case was designed to provide a gap to put the devices and bear the weight of a human body put on the seat plate. Regarding the weight of the robot as a design variable which can affect the stability criteria and derive performance, the parts of the base structure were designed and analyzed using ANSYS® software to provide the best mechanical behavior under load and having the least weight possible. It is to be said that the material of this linkage would be made up from aluminum alloy profiles [1].

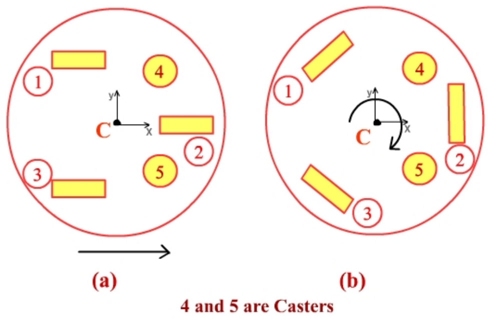

Figure1 Five wheeled locomotion mechanism with two castors and three drivers, (a) Navigation forward, (b) Changing direction.

As the seat is to be used by a paraplegic patient, not only an ergonomic design is needed but also the seat and the seat back should be equipped with supports in addition to arm rest. Furthermore, in order to prevent bed ulcers on numb and paralyzed members of the user's body, it would be an asset to have a cushion on seat and back surfaces that will damp concentrated pressures on patient's skin and allow blood circulation through the outer tissues. The alluded device is shaped from a contour of egg shaped rubber tubes which are inter-connected and filled with air [1].

It is to be said that knee and ankle joints rehabilitation mechanisms and an innovative passive standing mechanism were designed and fabricated on the robot unit in the last phase [1]. (Figure 4, Design and Simulation section)

4 Design optimization for dynamical tipover avoidance

Since dynamical behavior and stability of the nurse robot is the most important factor for a robot that serves in hospital environments as paraplegics and medical teams assistant, a dynamical analysis and simulation is necessary before any prototyping or usage of the designed mechanism and parts.

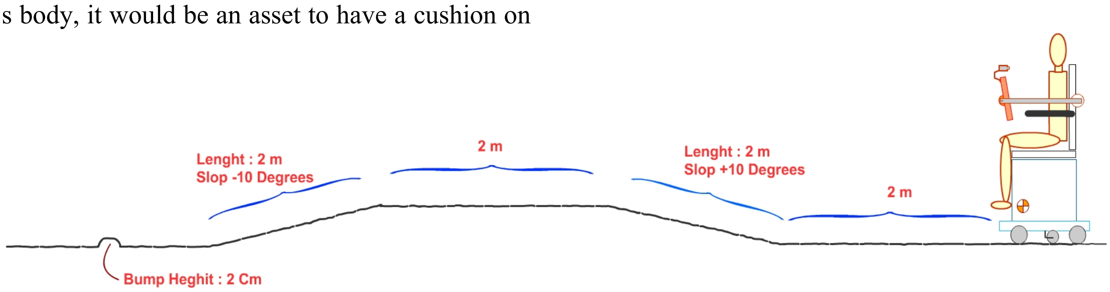

Figure 2 The hospital virtual path generated for robotic nurse unit to be used in dynamical simulation

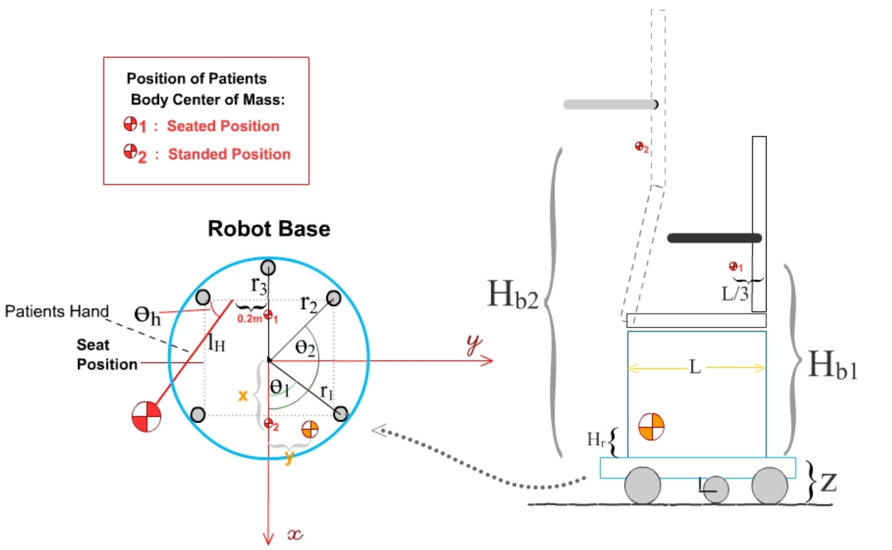

Figure 3 Robotic nurse unit locomotion and steering mechanism design parameters.

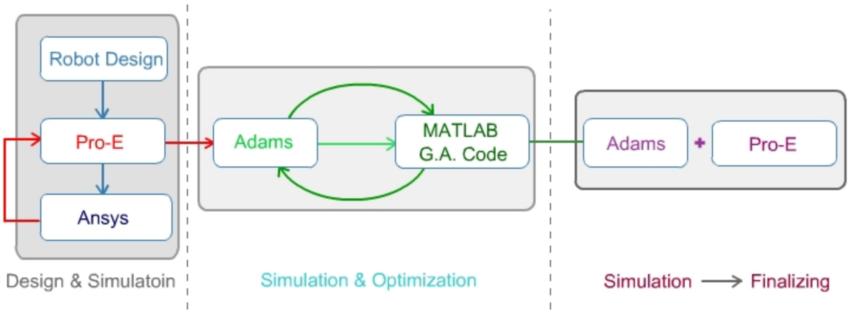

Figure 4 Block diagram, illustrating the procedure of tasks performed

Regarding international standards for architecture and building of a hospital, some parameters for our dynamical analysis were chosen similar to actual qualities and quantities in a standard hospital. Some of them were considered as follows:

1- The width of hospital corridors is 2.5 to 2.75 m.

2- The maximum slope in hospital floor can be 10 degrees.

3- The material used in ground is mostly soft polished concrete, HDF[1] (or wood fibers) and Epoxy resin compounds.

4- Mostly, the floor surface is such that can be assumed smooth with no disturbance or bumps [20].

In dynamical simulation of the nurse robot in hospital environment, a sample path was generated and given to ADAMS® (dynamical analysis software) as ground surface which is a combination of possible tracks which the robot may get through. As in Some environments a bracing or shield on the floor may cause a disturbance (bump) to the robot locomotion mechanism, a semi-cylindrical bump with 2 Cm height was also observed in the virtual modeling procedure. The whole ground path used in simulation is illustrated in Figure 2.

Moreover, while the stability of the robot was to be determined in any location or position, a Genetic Algorithm (GA) was designed and employed such that optimizes nurse robot's mechanical parts and mechanisms design parameters in order to obtain an optimally stable robot. Using the dynamical simulation of the robot in a virtual hospital environment, the GA mentioned is to optimize the robot to have the best stable and the safest navigation.

Optimal robot mechanisms design, due to stability is one of the most important parameters for tipover avoidance. For this case the locomotion and steering mechanism design parameters is shown in Figure 3.

In formulation of the optimization problem, considering design features assumptions, the best maneuverability and obstacle avoidance of the robotic unit to turn in spot, lead to symmetries in angular and radial positions between two front driving wheels as well as between two castor wheels with respect to x axis. According to Figure 3 in this optimization problem, formulation is as bellows:

$$\begin{cases} \sum M_x = 0 \ \Rightarrow \\ (F_1 - F_5) r_1 \sin\theta_1 + (F_2 - F_4) r_2 \sin\theta_2 + m_H g (l_H \cos\theta_H + s) = 0 \\ \sum M_y = 0 \ \Rightarrow \\ -(F_1 + F_5) r_1 \cos\theta_1 - (F_2 + F_4) r_2 \cos\theta_2 \\ + F_3 r_3 + m_R g x + r_B m_B g + m_H (l_H \sin\theta_H - r_B) = 0 \end{cases} \qquad (1)$$

F_i : Robot wheels upward forces $(i = 1,\ldots,5)$

r_i : Radial position of robot wheels $(i = 1,\ldots,5)$

θ_i : Angular position of robot wheels $(i = 1,\ldots,5)$

m_R : Robotic unit mass

m_B : Human body mass

r_B : Radial position of human body center of gravity

m_H : Hand disturbance load mass

l_H : Human hand length

θ_H : Human hand rotation angle

S : Human shoulder length

X : Robot center of gravity position

Where the nominal parameters of the robotic nurse unit are as bellows:

$$l_H = 600\ mm,\ m_H = 5\,kg,\ m_R = 40\,kg,$$
$$m_B = 60\,kg,\ r_{Bseated} = -\frac{40\sqrt{2}}{3}\,cm, \qquad (2)$$

In optimization of wheels locations the nurse robot base due to tipover avoidance during serving in hospital areas, since the patient may sit on the robot and travel around stability measures should be applied to all of the parts of the simulation which is run in every step of optimization. As in situation mentioned, concerning that almost all of the paraplegic patients can use their hands, the client may pick or hold a particle or device, parameters regarding these movements were concerned in stability analysis. Regarding human ergonomics and Handbook of biomedical instrumentation and measurement [21], patients seated location was calculated and used in

[1] High Density Fiber

stability analysis during the optimization. A method similar to Force-Angle tipover stability margin measure proposed by Rey et al [22] was employed to decide the stability criterion.

Concerning the Figure 5, the wheels contact points create a polygon with five ground contact points (n=5). Letting S_i stand for *i*th ground contact point S_c represents the instantaneous inertial location of the system center of mass. As stated above, three masses m_R, m_H, m_B can be considered in the analysis.

To decide the S_c ,

$$S_c = \frac{\sum M_i S_{mass\,i}}{(m_R + m_B + m_H)} \quad (3)$$

The lines which join the ground contact points are the candidate tipover axes, a_i , and the set of these lines are named support polygon. The *i*th tipover mode axis is achived by:

$$a_i = S_{i+1} - S_i \qquad i = \{1,...,n-1\} \quad (4)$$

tipover of the robot will always occur about the tipover axis a_i . By finding the *Sc*, in seated position of the patient on the robot using the formulation mentioned above, tipover status would be when the component of *Sc* on the support polygon plane points to a point outer the support polygon or in other words the center of mess for the whole system in a position far from center of the robot base that may cause a big tipover moment that makes the robot unstable. Finding the tipover axes, by studying the tipover status over every tipover axes, which are five in number, a measure can be attained that shows whether the robot would be stable in the situation chosen and which a_i is the most likely for tipover. To reach an optimum point for every wheel location under the nurse robot, as mentioned before Genetic Algorithm was used. A program code was generated in MATLAB® Software to find the optimum values as r_1, θ_1 radius and angle for front drive wheels, r_2, θ_2 radius and angle for front drive wheels and r_3 the position for the rear drive wheel using the dynamical simulation results of ADAMS® software outputs (run for the path illustrated in Figure 2). Moreover, location of the center of mass of the robot in the *XY* plane was another parameter to be optimized. Since the patient may pick or hold an object in the range of $-\pi/6$ *to* $\pi/2$ radians shown in Figure 6, that causes change in center of mass location as shown in Figure 6, optimum points $(r_1, \theta_1, ...)$ where generated for the best stable mode as well as deciding the optimum location for the center of mass of robot. It is to be mentioned that for the best result of 7 optimization parameters, number of population was set to 14, and number of iterations was 500. The optimization program was designed to give the results as matrixes and graphics in polar coordinates which show the robot base and the points attained. Figure 6 demonstrates the optimum answer of the Genetic Algorithm optimization on dynamical simulation outputs which was used in design and fabrication of the robotic nurse unit. In Figure 6, points illustrated with **O** are driver wheels and points shown with ► are caster wheels.

5 Robotic Nurse Unit Prototype

According to the results of dynamic simulation and optimization of design parameters due to tipover avoidance, the mechanical parts of the robotic nurse unit are designed and the prototype is fabricated in the Center of Excellence in Design, Robotics and Automation (CEDRA) at Sharif University of Technology (Figure 7) [1]. Recently, nurse robot team works on controlling and utilizing the final prototype in hospital environments.

6 Conclusion

To this date, the nurse robot designed in the Center of Excellence in Design, Robotics and Automation is a unique and complete robot which can serve in hospital areas especially paraplegic patients.

The necessity of employing Nurse Robot to assist paraplegic patients is proven concerning the lack of professionals and the vast number of paraplegics. The robot containing a perfect collection of required devices and mechanism for nursing a paraplegic such as passive standing, mobility assistance and rehabilitation systems is the most powerful design ever employed. Considering the vital role of such robotic unit, in optimum design and dynamical analysis and simulation process of the nurse robot in hospital environment, a remarkable effort was made and a realistic path for navigation was generated. To attain the best performance of the prototype, using genetic algorithm in cooperation with dynamical simulation results, the placement of driving and caster wheels as well as the supreme location of robot's center of mass was achieved and the optimization results were used in fabrication of the prototype. In a set of experiments designed to check the stability margins, the fabricated robotic nurse unit showed excellent robustness to the patients' movements on the seat and disturbances which cause tipover.

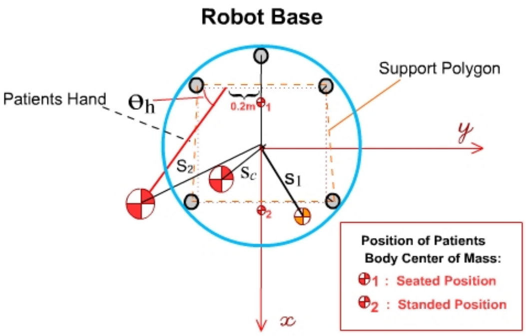

Figure 5 locations of Centers of Mass for every part of the system, support polygon, total Center of Mass.

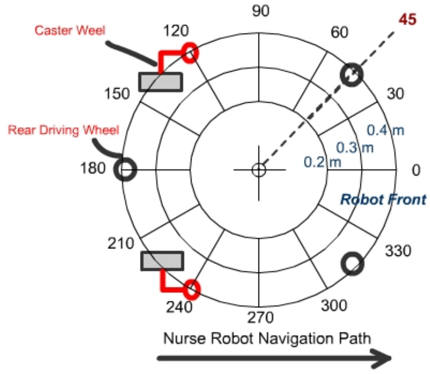

Figure 6 The optimum locations of Nurse Robot's center of mass and wheels location

Figure 7 Fabricated prototype of robotic nurse unit, Mechanical structure.

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