Design of an ultrasound based robotic system for assistance to the paraplegic and sickly.

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Abstract

While trying to assist the paraplegic and sickly, healthcare personnel encounter challenges in lifting them up, which result in some suffering from disabling back injuries. Furthermore, the introduction of health 4.0 has shown that application of Artificial Intelligence, robotics, and automated systems is the future. Therefore, to achieve sustainability, and improve the quality of life for both healthcare professionals and patients, innovative research in these fields is crucial. Thus, researchers propose the design of an ultrasound-based assistance robot to help carry the paraplegic and sickly. Its objectives being able to: carry the sickly and paraplegic to and from platforms, including moving with them up or down stairs. Inventor and blender have been used to model and simulate the proposed systems, respectively. Pulse-echo principle and Newtonian mechanics principles were used to develop the scientific model of the assistance robot. Results showed that for a robot to safely lift a patient weighing 100kg to a height of 1.1m above the ground a power of 107.91W is required and the maximum velocity it can reach is 0.15ms-1. Simulation results showed that, the robot will run smoothly without failure. It was recommended to sanitize the robot after it carries each person. Future studies on the design of assistance robots that are fully autonomous has been proposed. Overall, this research focused on how industrial delivery robotic systems can be adapted in healthcare to help achieve sustainability in healthcare, improve safety of the paraplegic and sickly, and reduce risks of endangering lives of healthcare professionals.

Keywords: Artificial Intelligence, Health4.0, Healthcare, Paraplegic and sickly, Robotics, Sustainability, Ultrasound.

1 Introduction

Throughout the years, paraplegics and the sickly have had a problem in navigating their way around a normal homestead or medical institution, particularly when going up and down the stairs, a task even a wheelchair cannot perform. Paramedics and guardians also experience problems in lifting, placing, and carrying them to different destinations without failure. Edlich et. al. (2005) wrote a journal based on the devastating injuries in health care workers. The injury in issue being the back injury caused by manual lifting of patients. This was a problem as many United States healthcare workers had disabling back injuries therefore a 'No Manual Lift' policy was to be instituted throughout the country. Which is a policy that must be put in Zimbabwe as well. According to Blorstad et. al. (2012), estimated back injuries accounted to 4.6% of all reported injuries in the healthcare workers in Pennsylvania, which is actually a matter to be taken into consideration. Further, patient falls in medical institutions have been a worldwide problem. Therefore, due to this study an initiative has to be taken to put the ultrasound based robotic system to use.

1.1 Background

Paraplegia is partial or complete paralysis of the lower half of the body with involvement of both legs, usually due to injury or disease of the spinal cord in the thoracic or lumbar region. According to Goto et. al. (2012) paraplegia is caused by a homozygous mutation of C12 or f65 (gene). Eck et. al. (2011) states that paraplegia is caused by adaptor protein complex 4 deficiency. Paraplegia may also be caused by severe spinal injuries, which is the most common case in Zimbabwe, due to a number of recorded car accidents. Therefore, it may be seen that anyone is in the risk of paraplegia and preventive measures have to be taken. These may include improving road safety as well as treating paraplegia in its early stages by therapy. Its symptoms are muscle weakness, weakness of the lower extremity, loss of muscle, stiffness or muscle spasms, reduced sensation of touch or leaking of urine or urinary retention, though

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medical diagnosis is greatly encouraged. In recent history robotics has been used in helping paraplegics get their way around physical obstacles in their everyday life. This paper seeks to design an ultrasound based robotic system for assistance of the paraplegic and sickly, that can lift up or set down a human up to 100kg from and onto a platform detecting the platform using ultra-sound.

2 Literature Review

2.1 Basic principles of operation in obstacle detection

Creating an inter-face that effectively operates without the use of vision is a task with difficulty, though achievable. The interface is usually applied to people who are visually impaired. Using systems such as voice recognition, gesture recognition and access technologies. The system with eyes-free interaction may be defined as a system that operates without visual attention. Helps in saving time as users may do other tasks whilst the system is performing its own tasks (Oakley, I., Park, J. S., 2007).

Abdul-Niby et. al. (2015) describes that an ultrasound signal, a signal of frequency above the audible hearing frequency is generated and transmitted by an ultra-sound transceiver/transducer. The transceiver is said to have the function to transmit and receive ultra-sound signals at the same time. Once the ultra-sonic signal moves, it travels in the air continually until it is obstructed by an object along its path. The ultra-sound signal will then bounce off the obstacle and will be reflected towards the transceiver. The reflected signal is then detected by the transceiver which on detection of the signal will send a pulse to the processor's input, communicating that an obstacle has been detected. Once the obstacle has been detected the robot will then change its course of movement. The ultrasound echo/es detected by the transceiver / receiver units are used to form echograms where detected echoes would be projected. The echograms are then analyzed; therefore, its signals are put in comparison with threshold values, helping distinguish between echoes from obstacles or those caused by interference. The analyzing of the echo helps determine the co-ordinates of the obstacle by determining the echo time.

2.2 Tactile sensors in humans

The human tactile system works through a number of receptors, so as to obtain some contacted tactile information. The main receptors are thermo receptors, mechanoreceptors and nociceptors. The mechanoreceptors detect vibration and pressure and, therefore are also divided into four parts. A tactile sensor is defined as a device that measures the information it gets from physical interaction with its environment, detecting mechanical stimulation. Tactile sensors have been widely used for detecting and calculating positions of center of pressure or the force applied on an object. Tactile sensors help in detecting the slightest forces exerted and hence help in the soft and careful carrying of patients. The measurement range is from 0 to 90 KPa, from the slightest touch of the human to the force of carrying the heavy human.

3 Material and Methods

3.1 Concept generation and selection

The robotic system was modelled using AutoCAD and Inventor 3D modelling software. Three assistance robotic concepts were generated using the above software and the best concept was selected using the binary dominance matrix. Concept three was selected as the optimal concept for further development.

3.2 Scientific modelling and motors sizing of the robotic manipulator

Pulse-echo principle, Newtonian mechanics, Ohms laws and Matrix algebra principles were used to developed the scientific model of the assistance robot. These scientific models were used to in sizing motors of the robot and determining the power consumption of the proposed system. Stainless steel has been used as the main material of the robotic system.

3.3 Determining the system maneuverability

Most areas where the robot will be operating are multi-story buildings. Therefore, sometimes the robot will be required to carry the patients up a staircase. Based on this, the maneuvering system of the robot should enable it to climb stairs. One way of doing this is adapting the tri-wheel system. The Tri-Wheel locomotion mechanism is a three-wheeled, spoked drive framework fit for two rotational modes: Driving and Tumbling Mode.

3.4 Determining the step height dimension

HC-SR04 sensor with high accuracy and stable readings range from 2cm to 400cm, has been used in step height determination. The amount of time taken for the sound wave to leave and return after bouncing off the target being measured is converted to a corresponding height.

3.5 Determining the general movement of the robotic system

The locus of points has been used to determine the general movement of the robot, that is, determining the positions of different links according to their joint movement with the other links. According to the Mirriam Webster Dictionary it is defined as the set of all points whose location is determined by certain conditions. It is a set of points that will all satisfy a given condition or a given property. Examples of the locus of points include

1. The set of all points equidistant from a point.
2. A set of all points satisfying a certain given equation.
3. Set of all points that are the same distance from two given points

3.6 System simulation

To check how the system will be operating in its wording environment, Blender was used to develop the simulation of the proposed system. Blender allows the user to visualize how the system operates in real time. Proteus has been used in circuit simulation and design of the proposed system.

4 Results and Discussion

Fig. 1. below shows the proposed system isometric view.

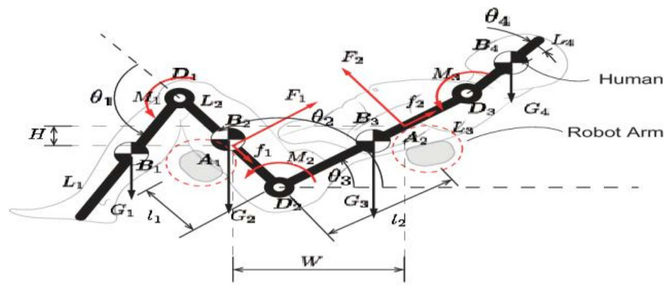

Fig. 1. Proposed system isometric view

Fig. 2. Shows the process of carrying a human by the proposed system

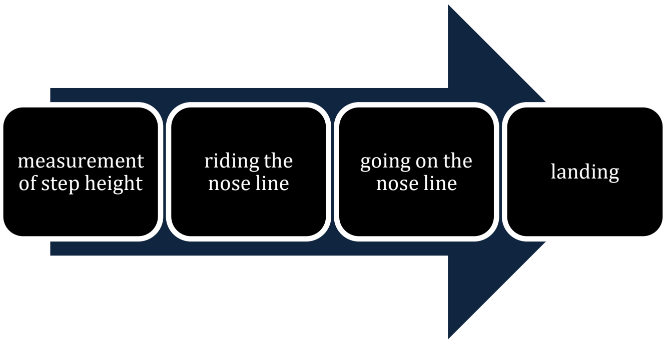

Fig. 3. Shows the flowchart of the process in which the proposed system climbs up the stairs whilst carrying a human

4.1 Practical energy modelling

Energy consumption is divided into three parts: The Sensor system, Control system and the Motion system.

Table 1. Variables and Values

Variable	Value
Ø	0.7
M	150
μ	0.745
ϵ	0.01
Δ	0.001
Λ	0.1
Φ	5

The variables that will be used during energy consumption of the proposed system calculations are summarized in Table 1 above.

Energy consumption of the Motion system.

$$E_{motion} = \int P_{motion} dt = E_K + E_f + E_e + E_m \quad (1)$$

Where;

E_k -kinetic energy

E_m -mechanical dissipation on overcoming friction

E_f -friction dissipation during movement of the robot

E_e -energy dissipation as heat

E_m -Energy consumption during motion.

Divide into three parts:

I. Standby (P is constant)
II. Startup (instantaneous pulse)
III. Stable operation(stable)

E_{motion} -energy consumed to attain and sustain motion

P_{motion} -power consumed during movement

Taking; $V_{max} = 0.15ms^{-1}$

$$E_K = {}^{Mv^2}/_2 \quad (2)$$

$$= \frac{150 \times 0.15^2}{2} = 1.6875J$$

$$E_f = \int (\mu \times M \times v) dt \quad (3)$$

$$= \int_0^{3600} 0.745 \times 150 \times 0.15 = 60.345KJ$$

$$E_e = \int (\in \times t^2 + \sigma \times v + \lambda \times t)$$

$$= \int_0^{3600} (0.01 \times t^2 \times 0.001 \times 0.15 \times 0.1 \times t) dt = 6.299 \times 10^6 J$$

$$E_m = \int \left[M \times e^{\daleth t} \times \cos\left(\varphi \times t + v + \frac{M}{2}\right) + M \right] dt \text{ and}$$

$$E_{total} = E_{idle} + E_{motion} \quad (4)$$

$E_{total} = 1.561 \times 10^{10}$ J

Where;

E_{idle} -energy consumed in the standby state

E_{motion} -energy consumed during movement

1. Energy consumption in the whole system.

$$E_{elec} = \int P_{source}(t) dt \quad (5)$$

Where;

E_{elec} -electrical consumption

P_{source} -source power

Consider, energy consumed in lifting the human body over a height of 1.1m

$$W_d = Mgh \tag{6}$$

$$=100\times9.81\times1.1 = 1079.1J$$

$$P = \frac{W_d}{t} = 1079.1/10 = 107.91W$$

NB: assuming the robot takes 10s to fully lift the human up that height

4.2 Robot climbing up the stairs.

Achievement of step height detection.

HC-SR04 sensor has high accuracy and stable readings from 2cm to 400cm

The amount of time taken for the sound wave to leave and return after bouncing off the target being measured is converted to a corresponding height.

$$s = f\lambda$$

Where;

S -speed of ultra-sound waves in the air ($343ms^{-1}$)

F -frequency of the sound wave (40kHz)

$$d = s \times t$$

d therefore is determined by multiplying the speed of the sound wave by half the total time of travel by the wave.

Sizing motors

$$T = Fr \tag{7}$$

Torque of the shoulder motor: T=100×9.81×0.22 = 215.82Nm

Torque of the elbow motor: T=100×9.81×0.32 = 313.92Nm

Torque of the wrist motor: T=2×9.81×0.15 = 2.943Nm

4.3 Proposed electrical system

Fig. 2 below shows the proposed system circuit design connections, that is, it shows how the actuators (motors), sensors (ultrasonic sensor), power supply (battery), and the Arduino uno microcontroller are all connected.

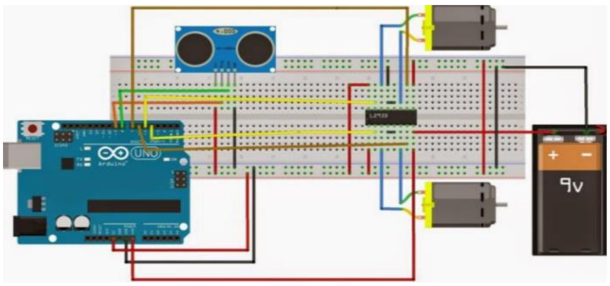

Fig. 4. Connection of proposed system's hardware

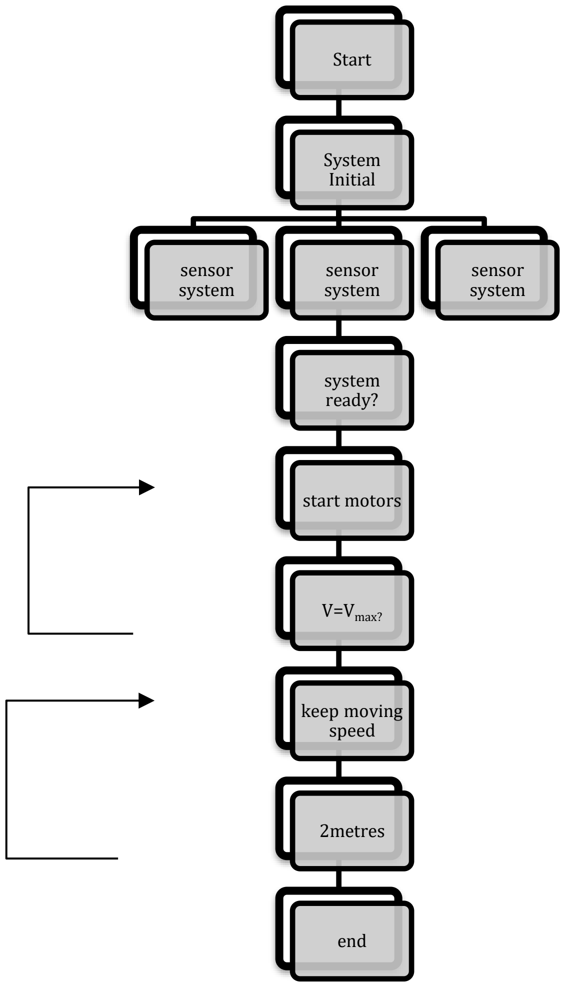

Fig. 5. Flowchart of how system works

4.4 Mechanical Simulation

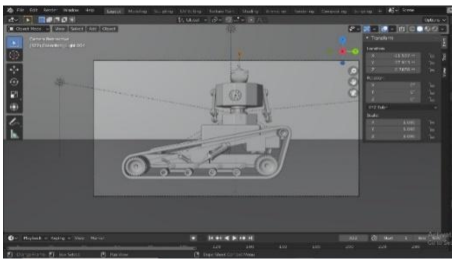

Fig. 6. Carrying motion simulation

The Fig. 6 above shows the simulation results' screenshot of the proposed system using Blender. This is a conceptual representation of the robotic system for analysis and testing.

5 Recommendations

It is recommended that the robotic nursing assistant be used in health care facilities under the supervision of healthcare personnel. The robotic nursing assistant must be sanitized after carrying an individual to remove and kill all viruses and prevent the spread. Researchers recommended that, further study on the development of a self-charging system in order to have a robotic assistant that is highly effective and can be used in highly isolated areas. Further research can also be done on the production of a full automated system without human supervision.

6 Conclusion

Health care personnel have been suffering disabling back injuries for years. Health care personnel also spend a lot of time on the energy-consuming task of carrying the paraplegic and sickly. The robotic nursing assistant will reduce the cases of back injuries, limit time wasting and as well save the energy of the health care personnel. The safety of the paraplegic and sickly is of paramount importance therefore the robotic nursing assistant will improve the safety of the patients due to its installed tactile sensing system. The robotic nursing assistant will reduce back injuries, limit time wastage and save energy of healthcare personnel. Calculations on energy have been done to see that the system is sustainable and logic tests of circuits, due to flow charts have been shown that the robotic assistant would run smoothly. Animations of the robotic actions have been done and show the movement of the links and wheels of the robotic assistant. Well labelled diagrams have been shown of the physical hardware of the robotic assistant. The researcher is therefore confident that the robotic nursing assistant will be adopted and used in health care facilities.

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