JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY (JKUAT)

DEPARTMENT OF MECHATRONIC ENGINEERING

BSc. Mechatronic Engineering

PROJECT PROPOSAL

PROJECT TITLE

DESIGN OF AN AUTOMATED HOSPITAL NURSE ASSISTANT

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INTRODUCTION

The number of health workers has been falling for years, and currently, there is a shortage of essential workers. The World Health Organization (WHO), at the Third Global Forum on Human Resource for Health, revealed the serious implications these shortages will have on people across the world [1]. Areas that are most affected are rural areas, which already have more than half the world's population taking residence, but only 38% of nurses and 25% of doctors working there [2]. Nurses are the most important of the "front line" workers, which makes it imperative for sub-Saharan countries to triple their numbers to achieve the Sustainable Development Goals for health [3]. Kenya is one such country, with the health system in the country facing many problems including drug shortages, understaffing and underfunding [5, 6]. For instance, in 2017 there were two dramatic and prolonged health worker strikes: doctors went on strike for 100 days and, soon afterwards, nurses followed suit for 150 days [7]. Such actions can cripple a health care system.

The health care system is never short of activity with patients coming into hospitals year in year out. This system should ideally have a good doctor-patient ratio, with enough nurses to assist the doctor in patient care. To increase the efficiency of services to patients, hospitals are always looking for innovative ideas to implement. These innovations are geared towards helping out doctors, nurses and other medical providers. Nurses have particularly been stretched thin with dwindling nurse numbers amid very high demand. Nurses handle most processes in a hospital or health centre, which means their job is that much harder if they are short-staffed. The COVID-19 pandemic has also demonstrated how fragile medical workers, particularly nurses are, and how much health services become strained when these essential workers are affected by the virus. The consequences are dire, with the loss of human life being substantial. Hospitals face financial losses and eventually end up being shut down.

These problems highlight the need to come up with a solution that can be implemented in the healthcare industry especially here in Kenya. The solution should be able to support nurses and other medical officers in their line of work. The solution is to be able to advocate and care for individuals and support patients through their illnesses. The solution should be able to help nurses in educating the patient to be able to understand their health, illness, medications and treatment. Furthermore, the solution should be designed in such a way that it is invulnerable to COVID-19 and other diseases which pose a great risk to nurses.

In this work, we describe the design of an automated nurse assistant robot to help specifically clinical nurse specialists and family nurse practitioners. This nurse assistant will not replace nurses but will be able to help out with basic services such as delivering drugs to the patient, recording medical history and symptoms, monitor patient health and record signs and symptoms and educate patients about their illness and health. The purpose of our design is to allow doctors and nurses to focus on actual patient care instead of routine tasks. Another purpose of our nurse assistant design is to reduce the strain hospitals face due to a shortage of personnel. We also hope to achieve a comprehensive reduction in the risk health providers face when tackling serious infections such as Coronavirus, Tuberculosis and Ebola. The nurse assistant will take charge of close contact with patients infected with the virus in operations that do not require the input of a doctor or nurse, such as the delivery of drugs and patient education on illness, treatment and medication.

Our design will be able to achieve the above functions if deployed accordingly. However, in order to meet all client needs, we need to ensure that non-functional requirements are also met. For instance, our design will have storage capacity adequate enough to serve multiple patients in one go. Our design will also be able to run for more than twenty fours hours without failure, enhancing its reliability and availability. Since our design will be applied in an environment not associated with technological minds, we will make sure it is easy to use, giving the nurse and other hospital time an easy experience. This will be accomplished using a user interface. Our design will also be able to have a humanoid face in order to enhance our conversations with the patient. Since our design will be storing user data, it is imperative that this information is secure, which will precipitate our inclusion of encryption into the systems' software. Database security must meet HIPPA requirements. The size of our design will be small enough to occupy the same space as hospital practitioners and patients without limiting the free movement of people. Most importantly we would want our design to be able to be fabricated locally. This would enhance its widespread adoption into the market, thus making it feasible for most hospitals to include it.

LITERATURE REVIEW

A robotic system is made up of both hardware and software, with hardware providing the physicality of the system and software that handles system operations. The two must be synergistically integrated to enable a robot to function as expected. Robotic systems are being increasingly integrated into several aspects of everyday life. Robotic systems are expected to assist or replace their human counterparts for the efficient and effective performance of all sorts of tasks such as industrial operations. In recent years, with the advancements in technology, healthcare is adopting and deploying robotic systems to help doctors in services such as surgical procedures. One example of this is the *da Vinci* Surgical Robot used by surgeons to make surgery less invasive and also less error-prone. This multi-armed system uses high definition 3D vision and is strapped to a surgeon's wrists and hands to make tiny, precise incisions. Such inventions revolutionized medicine, and with more sophistication, the future holds great things for the field of surgery.

Now, a further need arose when people discovered that nurses require help to reduce their workload, especially with the dwindling numbers of trained nurses. Some nurse assistant systems are being developed to solve this problem. Engineering students at Duke University in tandem with the National Science Foundation are developing a robotic “nurse” to assist human nurses. This robot nurse is called Trina (Tele-Robotic Intelligent Nursing Assistant) and can perform basic tasks such as delivering pills, cups and bowls, although not efficiently [8].

The Massachusetts Institute of Technology is training a robot nurse assistant to schedule various services such as assigning a ward to a particular patient. This is achieved using artificial intelligence [9].

If we keep looking, more and more nurse assistant technologies are being developed. Hstar Technologies have come up with a Robotic Nurse Assistant (RoNA) system which provides physical assistance to nurses in a health centre. It has a humanoid design with electric actuators that provide the flexibility and strength to lift patients. The system also employs an intelligent navigation system with perceptive abilities and 3-dimensional sensing [10].

Another system developed is called ARNA. It is an omnidirectional mobile robot designed with a robotic arm with six degrees of freedom. ARNA is used to assist patients in waking and pushing heavy items. This functionality is aided by a force-torque sensor which enables the robot to detect the patient’s navigational intent and adjust the amount of force applied.

ARNA has an interface module through which it receives information or puts out information from navigation sensors [11].

Carnegie Mellon University in the United States developed a nurse assistant code named Pearl to be deployed in senior centres and nursing homes to assist nurses in taking care of the elderly. Like ARNA, Pearl helps patients in walking and escorts patients to various places within the nursing home for appointments and other activities. Pearl has a human component as it has been fitted with an articulated head unit with facial expressions on a visual display [12].

Robotic research has taken a new turn in recent times with the development of Social Assistive Robotics (SAR). This can be defined as the merging of the traditional robotic applications, assistive and interactive functions. This merger creates a social aspect in robotics. Active research projects on the same include Brian (2008), SIRA (2005) and Clara (2005) in [13, 15, 16, 17]. The Brian project aimed at equipping robots with a better awareness of a patient's status through recognition of the patient's pose and gestures. This is the social intelligence aspect being explored in such research. As a consequence, the robot makes better decisions in accomplishing its job. As noted, artificial intelligence is incorporated, with reinforcement learning used to train the robot on emotions to facilitate bi-directional social communication. Such robots have been used in trials and found to have similar therapeutic value to animals. Communication and interaction with patients is the defining factor in these studies [17, 18].

METHODOLOGY

We used a modular approach when solving this problem. We broke the components down into mechanical, electrical and computing. This was to help us solve the problem easier. We later on combined the modules together forming a mechatronic system that is fully integrated. We code-named our nurse assistant Salma.

Mechanical

We had different mechanical modules, namely a humanoid head, robotic arm, mobile platform and storage boxes. Our humanoid head provides the interface where a patient or other nurses can interact with Salma using speech. The robotic arm was used to pick and place drugs from the storage boxes onto the patient's table. Storage boxes were used to store the drugs from the pharmacy to the patient's room while in transit as shown in Figure 1. We used the mobile platform to provide Salma with the ability to move around in the hospital while moving with the drugs in batches.

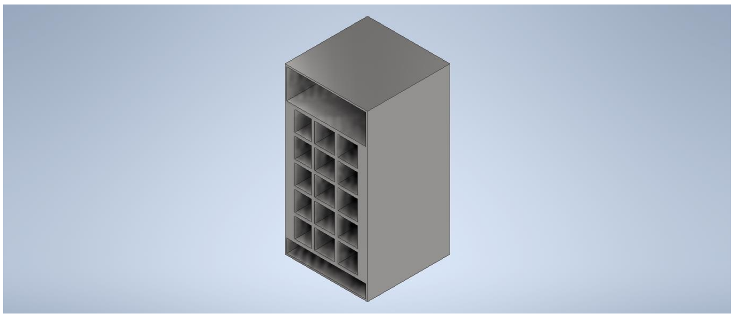

Figure 1: Storage boxes

Salma has a humanoid head as shown in Figure 2. The skin material used to construct the face of Salma needs to be deformable to be able to express different facial expressions. Synthetic silicone rubber is used as the skin, but since this material isn't locally available we planned on using plasticine. Plasticine is readily available and its stiffness can be controlled. We will use hand moulding to fabricate the skin onto the humanoid head. In order to reduce the complexity of the design, we will not implement a control point. We would have a series of electric actuation mechanisms developed in order to provide motion to the eyes and lips. In order to achieve various facial expressions on a humanoid head, modern designs incorporate a large number of actuators in the system which raises issues like system complexity, complicated control protocols, and undesirable weight and energy consumption. For our design, the servo mechanism is at the back of the head while the parts in the face are controlled by bourbon cables. These are essential as they provide action at a distance. Due to the lack of small, compact and powerful mechanical actuators, it is not possible to place the actuation mechanism at the point of action [21].

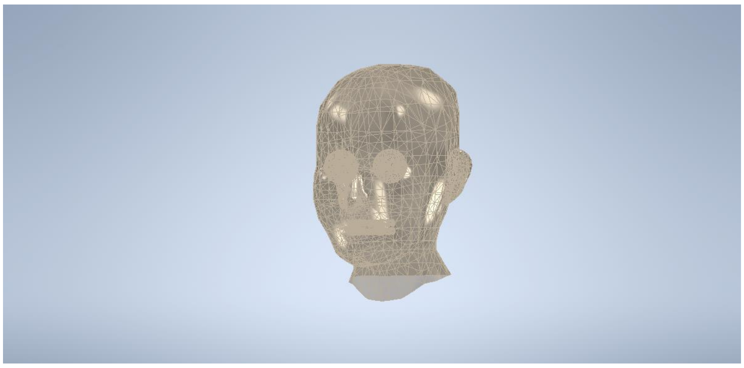

Figure 2: Humanoid head

Salma will have the capability to move around, and in a modern hospital where there is a lift. Wheels used for mobility are shown in Figure 3. Salma will use her robotic hand as shown in Figure 4 to push buttons in the lift enabling her to easily traverse the hospital. There will be black visual lines embedded on the floor that guide the direction of the robot to individual wards. Once Salma reaches the door, there will be a near field communication (NFC) tag that contains read-only data which specifies information on the specific ward. NFC tags are used for wireless communication of information in a very short time. If Salma detects the room where she needs to administer drugs she will enter. Furthermore, Salma will be equipped with a camera that acts as her eyes to navigate the hospital and avoid tangling with humans or figuring out which button to press on the lift.

The wheels are able to be sourced at a local store, 260mm x 120mm wheels from Nerokas. They are able to support up to 12kg load. We would have wished to use mecanum wheels as they are omnidirectional and have a load capacity of 20kgs for a 1600mm wheel but they are rather expensive. These wheels are able to achieve bidirectional mobility of the robot.

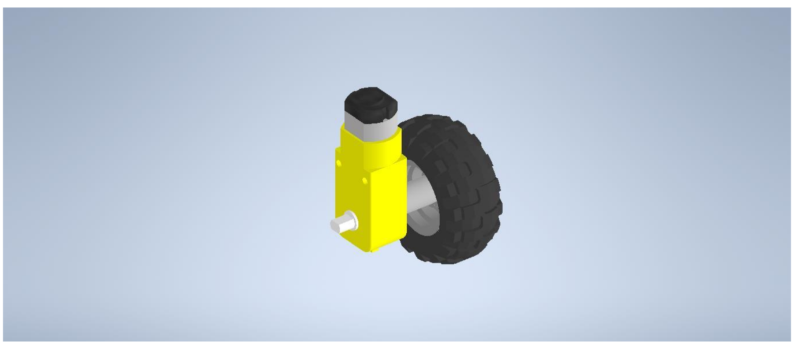

Figure 3: Wheel Assembly

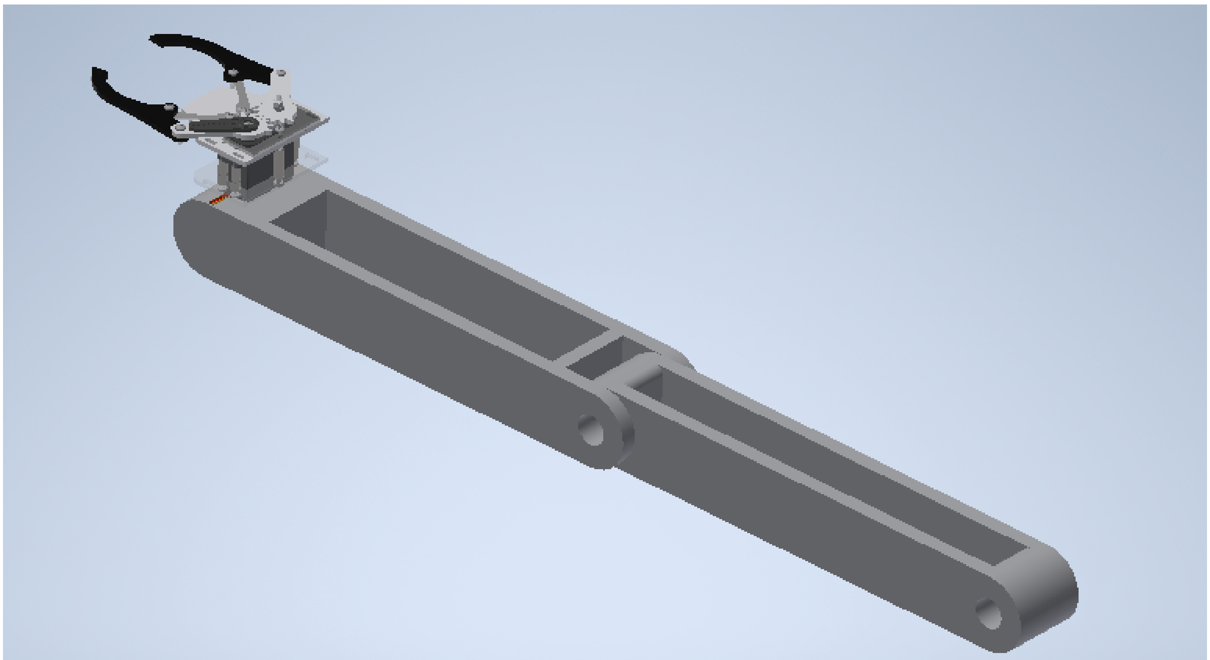

Figure 4: Robotic arm

The speed of our robot will be determined using the velocity equation shown below:

$$Velocity = 2 * \Pi * (radius\ of\ the\ wheel) * rpm$$

Rpm is the rotation of the DC motor under load.

The wheels can only move forward and backwards but we can be able to achieve near-omnidirectional mobility by programming the DC motor accordingly thus achieving more motions. If we want to make a sharp right turn we need to increase the speed of the wheel in the outer parts of the mechanism and also reduce the speed of the wheel in the inside part as shown in the figure below.

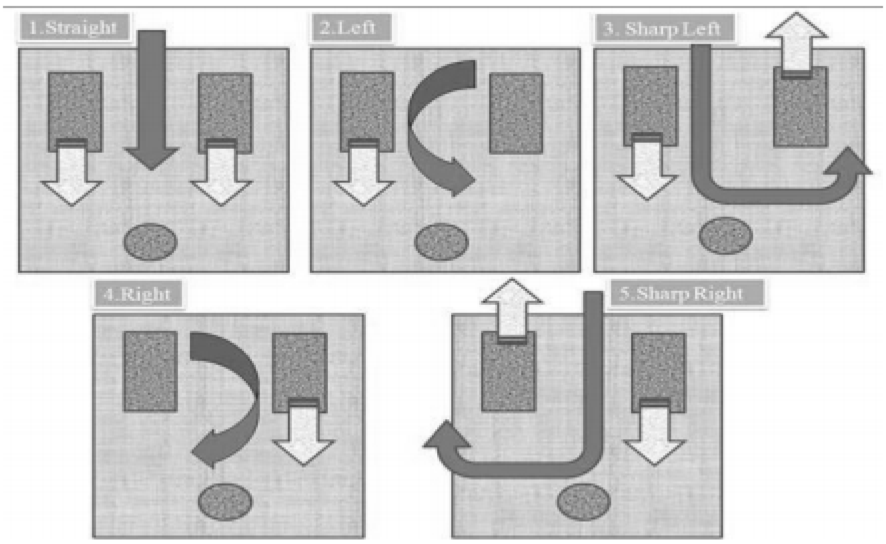

Figure 5: Movement of robot wheels

The robotic arm on Salma will be able to take trays of drugs from storage boxes to the respective patients' tables and return the trays back to the storage boxes. This means it should have the ability to lift, move, lower and release an object [23]. We also intend for the robotic arms to be able to push buttons when using the lifts. We put into consideration the following material properties during the material selection process: strength, lightness and availability. The material should have sufficient strength to ensure the linking of each arm and be able to carry a load of up to $9.81N$. The links should also be able to bear the load distribution as well as the motors which will be running [24, 25]. The lower density of the material minimizes the torque required for the actuators to work. The material should be easily available in the market because fabrication would be done locally. Aluminium satisfies our criteria because it is easier to work with, it's relatively soft and easier to cut, it is about one-third of the weight of stainless steel and it is cheaper than stainless steel due to weight to volume ratio. Its lightness is a key advantage because it minimizes the torque requirement of the robot actuators.

When obtaining suitable design parameters we did a kinematic analysis in order to define position relative to a frame to its original coordinates. Using the kinematic model, a programmer can determine the configuration of input reference that should be fed to every actuator so that the robot can do coincident movements of all joints to reach the desired position. The kinematics problem consists of forward and inverse kinematics. Forward kinematics refers to the use of the kinematic equations of the robotic arm to compute the position of the end-effector from specified values for the joint parameters. Inverse kinematics will be applied to find joint variables from the end-effector position.

An actuator is placed at each joint in the arm to apply a torque which in turn creates motion by overcoming the resistance on the link due to gravity and inertia. Gravity creates this resistance by pulling the links towards the centre of the earth. An actuator with an appropriate rating high enough to overcome this gravity-induced resistance is therefore required. This forms the basis for our torque calculations as described below. In order to calculate this torque, the completely stretched out arm is selected for analysis. This is because the resistance on a joint due to gravity is dependent on the robot's pose, and the torque on the shoulder joint is greater when the arm is horizontal.

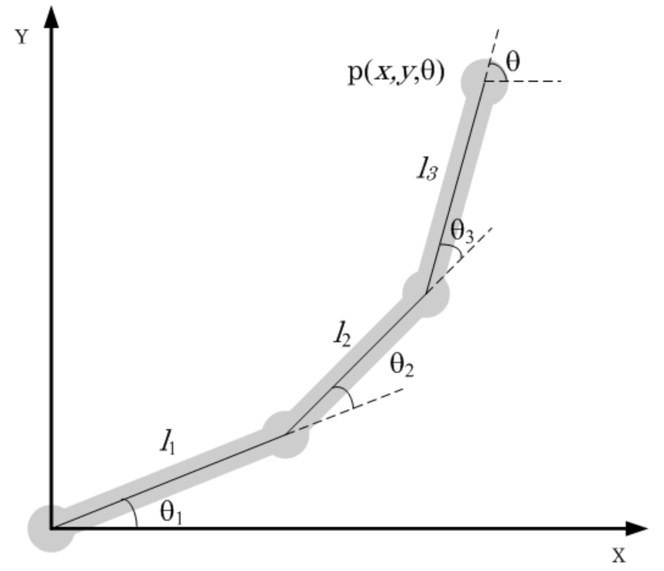

Figure 6: Kinematic analysis for 4 bar robotic arm

$$x = l_1 cos(\theta_1) + l_2 cos(\theta_1 + \theta_2) + l_3 cos(\theta_1 + \theta_2 + \theta_3)$$

$$y = l_1 sin(\theta_1) + l_2 sin(\theta_1 + \theta_2) + l_3 sin(\theta_1 + \theta_2 + \theta_3)$$

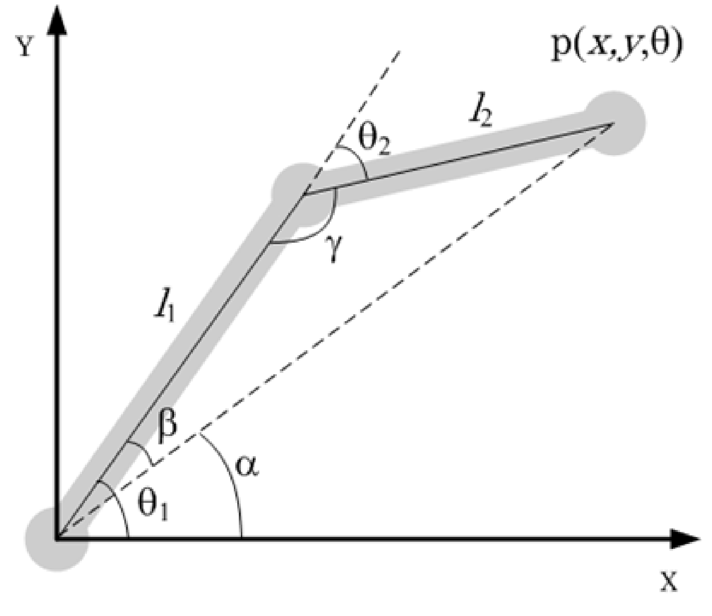

Figure 6: Kinematic analysis for 3 bar robotic arm

With cosine law, we get

$$(x_2 + y_2) = l_{12} + l_{22} - 2 l_1 l_2 cos(180 - \theta_2) \qquad eq\ 2$$

Since $cos(180 - \theta_2) = - cos(\theta_2)$ the eq 2 will become

$$(x_2 + y_2) = l_{12} + l_{22} + 2 l_1 l_2 cos(\theta_2) \qquad eq\ 3$$

By solving eq 3 for getting $\cos(\theta_2)$

$$cos(\theta_2) = x2 + y2 - l12 - l222112 \qquad eq\,3$$

Therefore the θ2 will be determined by taking inverse cosines as

$$\theta2 = arccos(x2 + y2 - l12 - l2222l112)$$

$$sin(\beta)l2 = sin(\gamma)x2 + y2$$

$$\alpha = arctan(yx)$$

Where sin(γ) = sin(180-θ2) = sin(θ2). By replacing sin(γ) with sin(θ2), the equation 19 will become

$$\beta = arcsin(l2sin(\theta2)x2 + y2)$$

Since θ1 = β + α, the θ1 can be solved as

$$\theta1 = arcsin(l2sin(\theta)x2 + y2) + arctan(yx)$$

Electrical

We had different electrical modules, namely the wheels, sensory network, robotic arm and interface. The wheel's sub-section provides motion to allow Salma to navigate in the hospital. The robotic arm was used to pick and place drugs from the storage boxes onto the patient’s table and also to press buttons on entry to a lift. The interface is where Salma is able to communicate with the patient and other nurses. The sensory network is where Salma is able to get patients’ health conditions, body temperature, blood pressure, blood oxygen and electrocardiography. We would have wished for Salma to be able to take blood samples of patients but it is a complicated process since there has to be sterilization.

The wheels are driven by a motor driver, L298N, which is a dual H-bridge and therefore can be used to control two D.C motors that rotate clockwise and anticlockwise directions. The L298N can output 600 mA and 1.2 A peak values. The drive wheels are driven using two D.C motors and powered by the battery module. For the battery module, we are using a dual 2300mAh 14.8V Lipo Battery. These batteries are rechargeable and able to up to a maximum current of 4A. We would have chosen the lead-acid battery but they are heavier hence they would take up more load instead of using it to carry medicine. For power distribution, we are using buck converters as they have lower power wastage compared to voltage regulators. We are able to have 3 different channels of 3.3V, 5V and 12V. The rotations and switching of the motor are controlled by the Arduino ATmega microcontroller. The motor driver takes the input signals from the microcontroller and generates a corresponding output for the motor since it is a current enhancing device. The DC motor uses 6V and 6V to 12V drives, the gears which are decided by the ratings of the motor Supply voltage and logically, determine what input voltage is, either, high or low.

For the sensory network, we connect our sensors using a 12C bus which they can use to push data to the microcontroller. We have a DHT11 sensor to log the humidity and temperature of the hospital. The ultrasonic sensor is used in obstacle avoidance. It aided the camera in doing so. The 5 Channel Line Tracking Sensor Module is able to track the lines. With MAXREFDES220 reference design, which consists of a complete integrated optical sensor module (MAX30101 or MAX30102), a microcontroller sensor hub (MAX32664D) and a sensing algorithm, we are able to measure heart rate, blood oxygen saturation level (SpO2), and blood pressure. We utilized the Si1172, Silicon labs products to do single-channel ECG measurements. For multichannel ECG of up to 12 leads, we will interface the patient's room where the EC machine is connected. This will enable us to get the readings from an already existing sensor network.

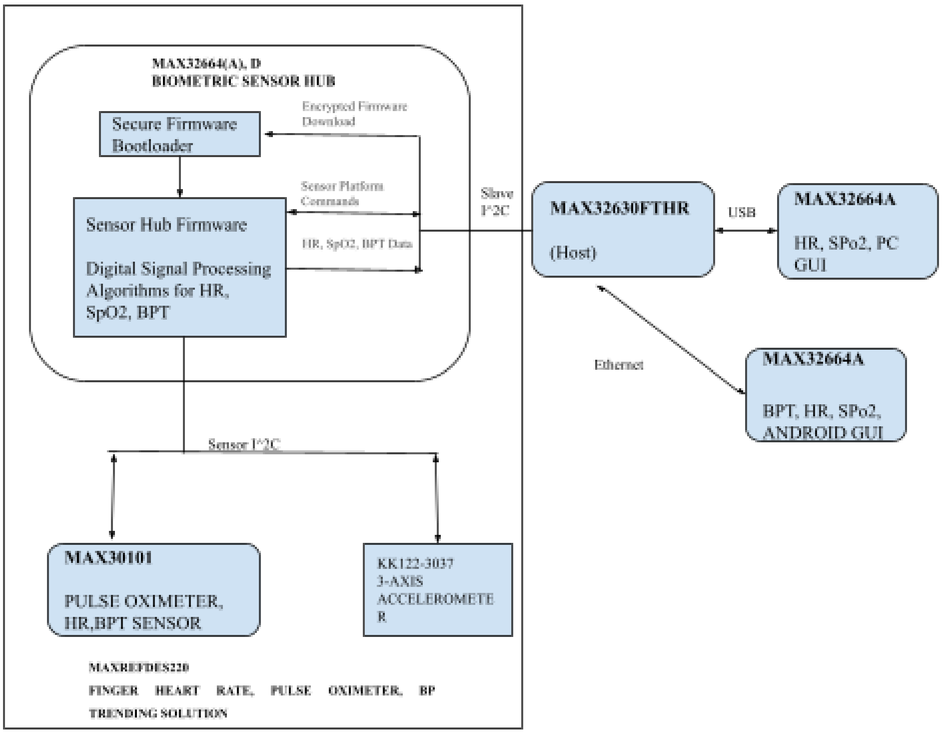

Figure 7: Sensory network

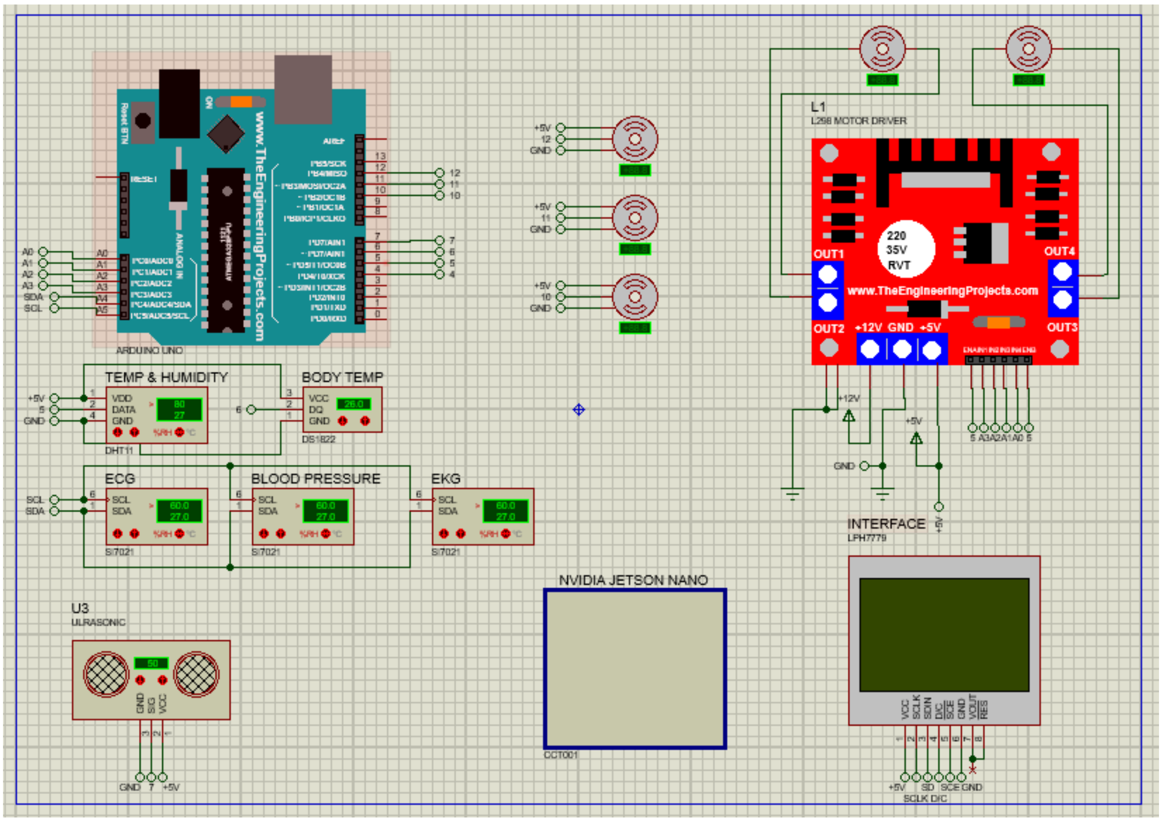

Figure 8: Electrical CAD

Compute and control

The Central Processing Unit is the actual brain of Salma. We have a dual redundant approach where we have a microcontroller and microcomputer. The microcontroller is used to handle light tasks such as driving the DC motors using a DC motor driver, driving the servos, getting sensor input data from the ultrasonic sensor and Infrared Red receiver. For the microcontroller, we are using the Arduino Uno. We would have wished to use the esp32 WROOM chip. It is equipped with a high-performance dual-core Tensilica LX6 MCU. One core handles the high-speed connection and the other for standalone application development. The dual-core MCU has a 240 MHz frequency. Since it is a 32-bit chip it will offer us a higher precision when reading sensory values. Utilizing free RTOS allows for each task to have a deterministic execution pattern and that every task meets its execution deadline. Two tasks were created, each running independently on their cores. Sensor readings were acquired during the first task. All remaining functions were implemented in the second task. The Microcomputer we chose was an Nvidia Jetson Nano. This is because it is a small AI computer that has the performance and power efficiency needed to run modern AI workloads, multiple neural networks in parallel and process data from several high-resolution sensors simultaneously. This offers us two great opportunities, to run our AI model on the device and

also get a backup for our Microcontroller. Jetson Nano offers us a Quad-core ARM A57 at 1.43 GHz, 2 GB 64-bit LPDDR4 and a 128-core NVIDIA Maxwell GPU.
Salma is equipped with a conversational AI. We are using recurrent neural networks which have shown great strides when it comes to text processing especially the LSTM network. We will use the AI to monitor patient health by inquiring about how he/she is feeling day by day. This will be logged and sent to the doctor. We will also be running a model to educate the patient on the drug he/she has been given by the hospital and also about the illness he/she is having. This will aid in the physiological development of the patient. It will ensure the patient is able to understand their health, illness, medication and treatment. We will also use an object detection model which will be used to avoid obstacles in the way of Salma.

Any system requires a control system to continuously read from sensors and update the commands for the actuators so as to achieve the desired robot behaviour, thus getting rid of errors.

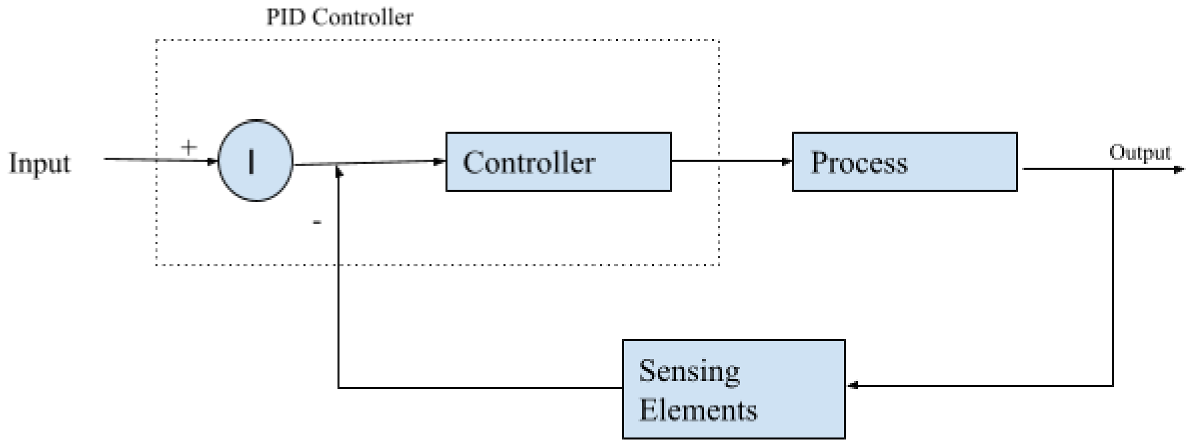

Figure 9: PID Control

For our design, we used a proportional integral derivative (PID) controller. This controller combines proportional control with additional integral and derivative adjustments which help the unit automatically compensate for changes in the system. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction. Integral tuning attempts to remedy this by effectively accumulating the error result from the proportional action to increase the correction factor. Derivative tuning attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

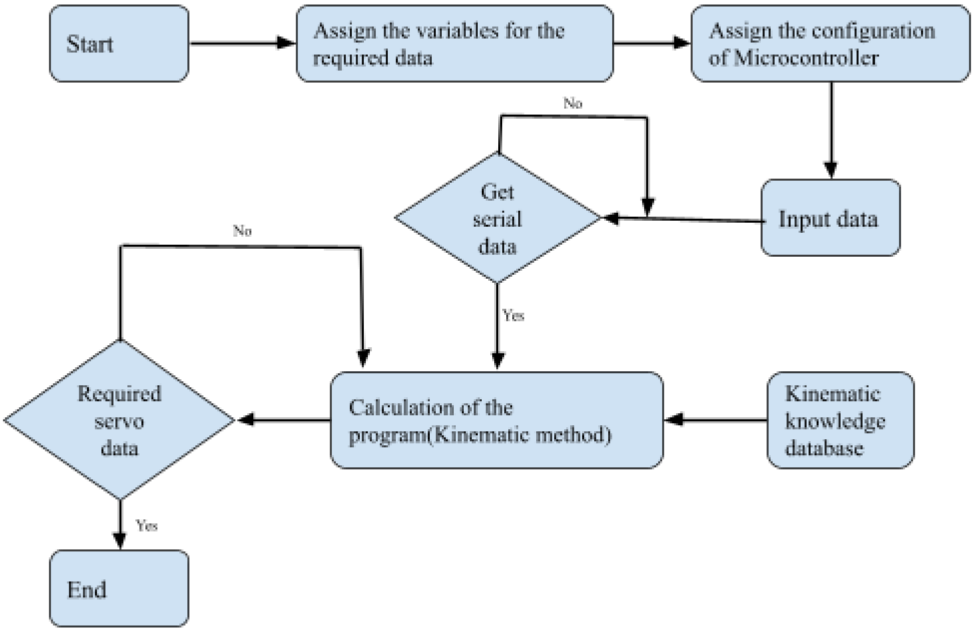

Figure 10. Program Flowchart of Robot Arm control program

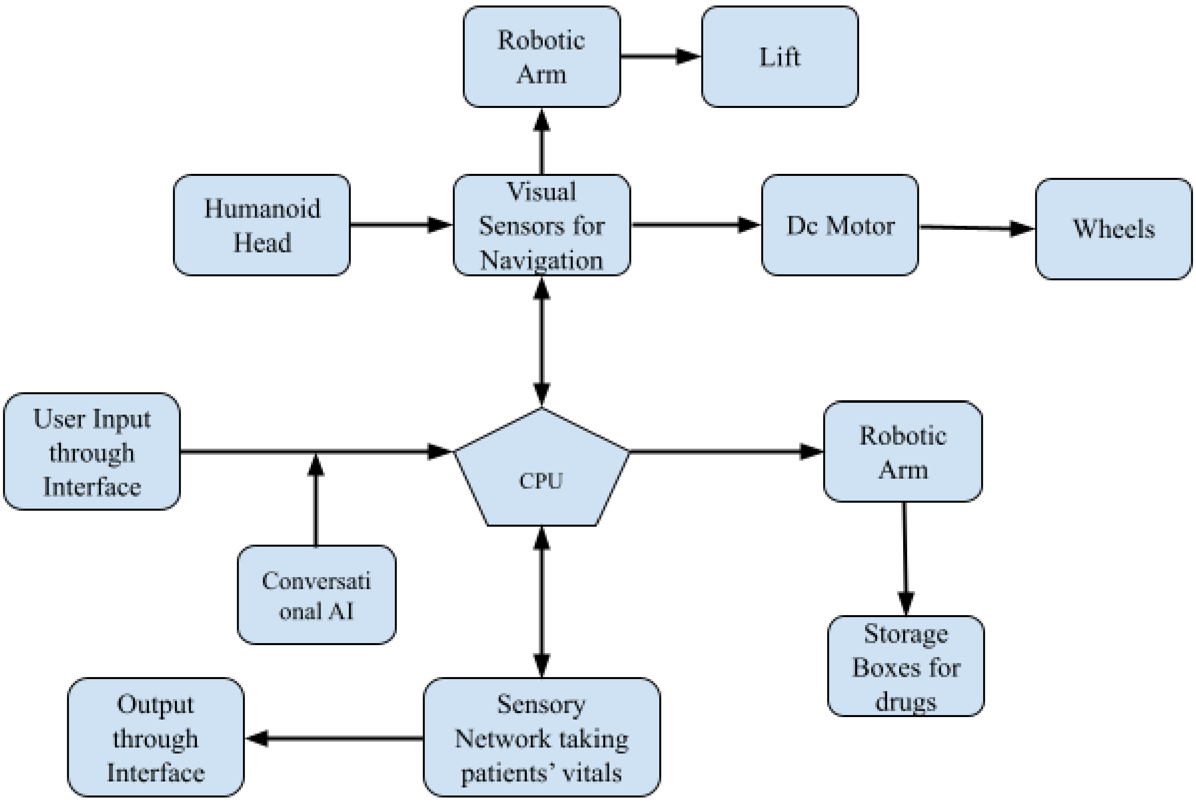

Figure 11. Process Flowchart

RESULTS

Based on our design we were able to come up with the inventor part and assembly designs as shown in *Figure 12*. The part diagrams are shown in the Appendix section.

We did a simulation test to see if our structure could hold the 10kg of load we had initially stated. We removed the head and the arm since they would increase more meshing nodes yet we don't have the compute power to do so. We then applied a 20kg load distributed on the frame and placed a fixed contact on the base of the wheel. We meshed our design and obtained 1127992 nodes and 606002 elements. From *Figure 13* we see that our wheels can bear our max load of 98.1N and the maximum displacement in the body as shown by Figure 13 is 0.9868mm.

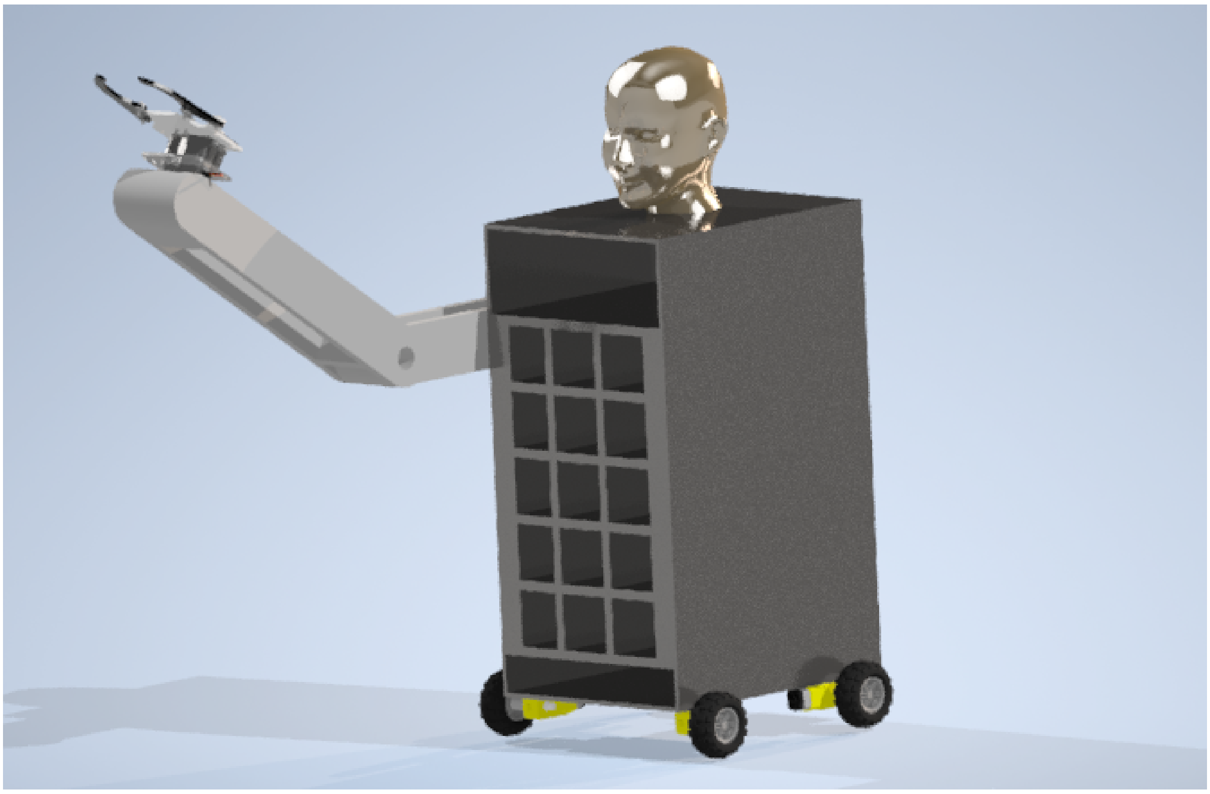

Figure 12: Assembly of Salma

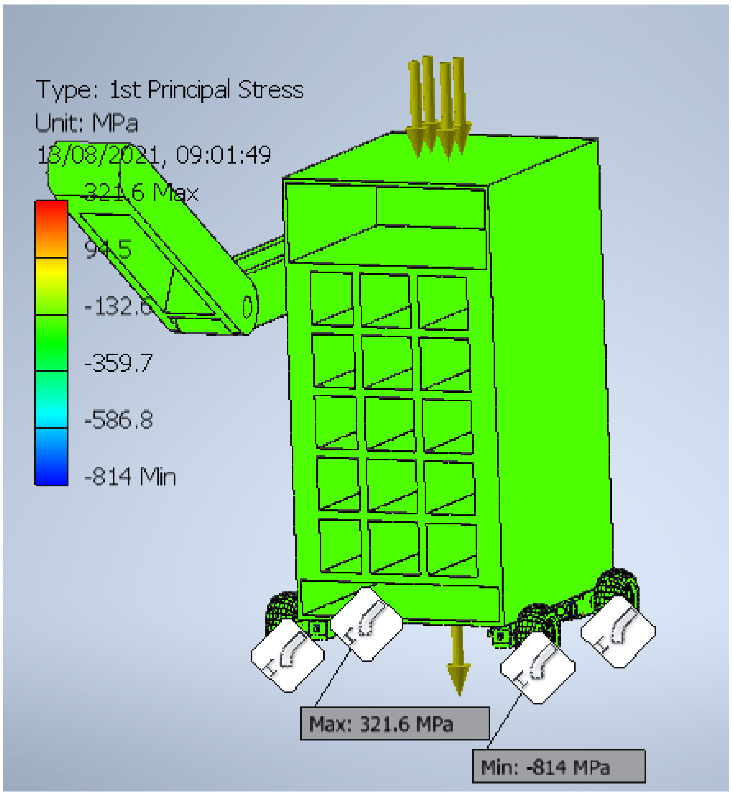

Figure 13: Ist Principal Stress

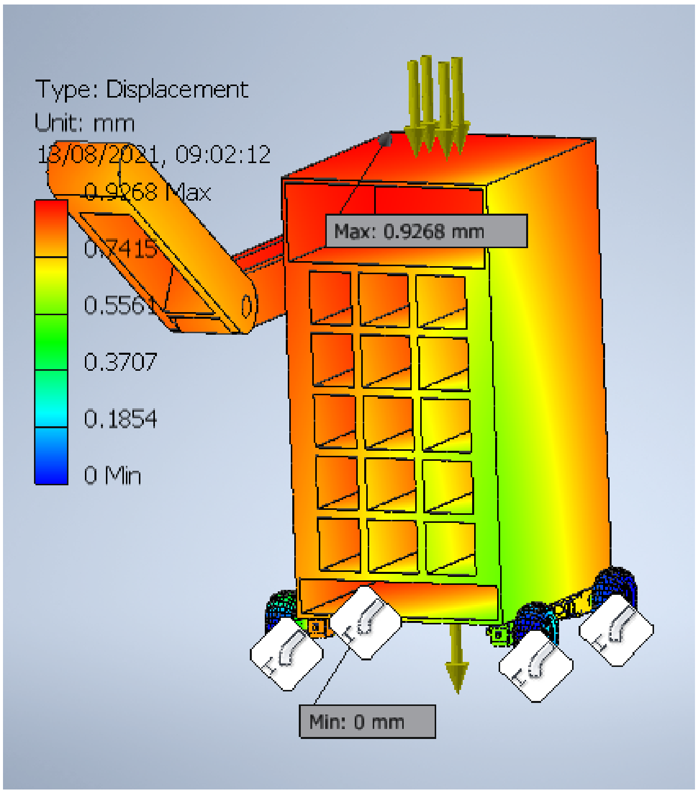

Figure 14: Displacement

CONCLUSION

From our initial objectives, we were able to produce a nurse assistant that can help nurses deliver drugs to the patient, help monitor the health status of the patient and also help educate patients on their illness, health, treatment and medication. Our design is structured in such a way that it will accomplish the set functions. It will navigate freely in a hospital, even going in and out of lifts. It will help both patients and hospital staff by having the capability to dispense drugs when required as well as monitor patient health. Another important aspect of the hospital experience for patients will be our design's capability to engage in educational conversation. Our design will not only be able to engage in the technical aspect of hospital functions but also the social aspect that most robots lack. This is achieved using artificial intelligence, which is the gateway to further technological developments. When our design is incorporated into the health care system, it will be able to offset the dire shortage of nurses and other health workers, especially during the ongoing COVID-19 pandemic. Furthermore, our design is a mechatronic design.

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APPENDIX

1. Github repository for the whole project.
   https://github.com/KelvinGitu/Design-of-an-Automatic-Nurse-Assitant