A Project Report

on

Design and Development of Intelligent Self-Balancing Stretcher

Submitted in partial fulfilment of requirements of the degree of

Bachelor of Engineering

in

Mechanical Engineering

Submitted by

Faizan Imtiyaz Kazi	**(M-15-0404)**
Atharv Vijayanand Joshi	**(M-15-0253)**
Gaurav Santosh Kadam	**(M-15-0089)**
Shaarif Yusuf Hamdule	**(M-15-0030)**

Under the guidance of

Prof. V. V. Nagale

सिध्दिर्भवति कर्मजा

Department of Mechanical Engineering

Finolex Academy of Management & Technology

(Affiliated to University of Mumbai)

MIDC, Mirjole Block, Ratnagiri - 415639

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Abstract

While transporting a patient through an ambulance he/she may feel discomfort throughout the journey. It may be because of steep or banked roads. Which results in an increase in blood pressure of the patient, making the situation worse. The existing technologies may not be sufficient to provide remedy for this situation.

The project intends to implement the principle of Gough-Stewart Platform in design and development of intelligent self-balancing stretcher. Gough Stewart platform is used for precise positioning of top platform with respect to its base. This logic can be implemented to balance or keep the stretcher horizontal by providing counter orientation.

In this project, the base of the Stewart platform is fixed to the ambulance floor and irrespective to the road conditions whether the ambulance is travelling on a slope or banked roads the stretcher connected with the top platform will remain horizontal. This will help the treatment by keeping the blood pressure under control.

The secondary objective aims at manually providing the stretcher a defined position with respect to the base by means of a controlling device. The stretcher can be adjusted in any orientation based on the preference of Emergency medical technician.

The project plans on employing the objectives mentioned above in the form of prototype, & required modification for this implementation in actual working model.

Keywords – Gough-Stewart Platform, Self-Balancing, Stretcher, Motion Compensation, Prototype.

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Chapter 1
Introduction

1.1 Motivation

Healthcare is a rapidly advancing industry which is essential for human longevity is an important aspect of everyday life that is always adapting to compete with changes occurring in the world. So, when a life-threatening accident requires an ambulance, everyone desires the best care and the highest probability of survival on their journey to receiving advanced medical care. While appropriate training of EMT staff can enhance the success rate of trips, progressions in the technologies that allow them to work safer and more efficiently provides a foundation for the advancement of the ambulance ride.

The ambulance stretcher is an equipment used in the healthcare sector that may be overlooked at times, but is a necessary step towards recovery of the patient. Ambulance stretcher can be vital in case of emergency conditions that is used by paramedic operator. But the ability of operators to handle the situation may falter because of lack of durability or poor design of stretcher.

Goal of this design is to maximize stretcher functionality and dependability, while increasing comfort to reduce further damage to the patient due to motion of the ambulance, induced due to different features like road conditions. The likelihood of saving more lives will increase drastically because of this project.

According to a study conducted at Worcester Polytechnic Institute by Jono Graziosi Et al. in 2010[1], after polling ambulance workers through multiple sources, it was obvious that the reduction in vibrations would greatly increase patient comfort level and their ability to provide care.

When polling the paramedics online and at local dispatch facilities it was clear that certain factors greatly decrease both the patients comfort level and the ability of the paramedics to provide care en-route. Road induced vibrations can be felt inside the patient compartment making it difficult to diagnose and treat patients. These vibrations can also cause pain and discomfort to patients being transported, especially those with spinal or neck injury and broken bones.

The wavy nature of roads in the Ghats are a major factor to be taken into consideration. When a vehicle traverses through such roads it experiences pitch and roll motions. The study conducted by K.Sagawa Et al.[2] describes that, frequent braking of the vehicle results in blood pressure variation which leads to further deterioration of a patient’s condition. The blood pressure variation can be reduced by tilting the stretcher and counter balancing the inertia which arises due to braking of the vehicle. It may also cause motion sickness, in addition, if the patients is on active ventilator support, or has his/her throat tracheotomized, or even has a saline injected into veins, a slight mishap could have devastating repercussions on patient’s health.

Hence, the project aims to reduce the motions transmitted to the patient.

1.2 Introduction to Gough-Stewart Platform

In search for a suitable means for simulating flight conditions for the safe training of helicopter pilots, the design of a mechanism has been established having all the freedoms of motion within the design limitations of amplitude and capable of being controlled in all of them simultaneously.

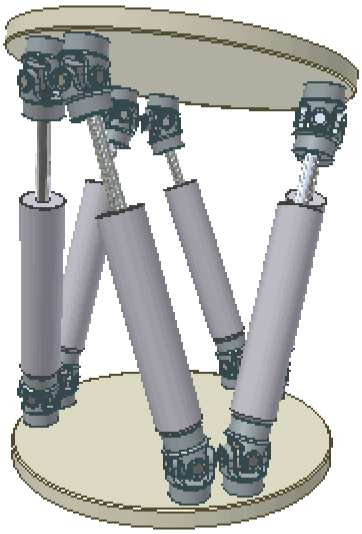


Figure 1

The design of the original Stewart Platform Et al.[2] has been modified over the years. At present, a Gough–Stewart Platform is a type of parallel manipulator that has six prismatic actuators, commonly hydraulic jacks or electric linear actuators, attached in pairs to three positions on the platform's baseplate, crossing over to three mounting points on a top plate. All 12 connections are made via universal joints. Devices placed on the top plate can be moved in the six degrees of freedom in which it is possible for a freely-suspended body to move. These are the three linear movements, viz., lateral, longitudinal, and vertical, and the three rotational movements, viz., pitch, roll, and yaw. Because of its motions, it is also called a six-axis platform or 6 degrees of freedom platform.

Scopes of the mechanism as suggested by D. Stewart are as follows:

(a) As a vehicle for representing a body in space subjected to all the forces which may be met with in its voyage.

(b) As representing a platform held stationary in space mounted on a vessel such as a ship which is subjected to the random movements of the sea.

(c) As a platform for simulating the actions of the helicopter as driven by its pilot.

(d) As a support for a helicopter which is capable of being driven by the pilot, random actions being applied to the supporting platform as prescribed.

(e) As any vehicle which is subject to control by a human being.

(f) As a basis of design for a new form of machine tool.

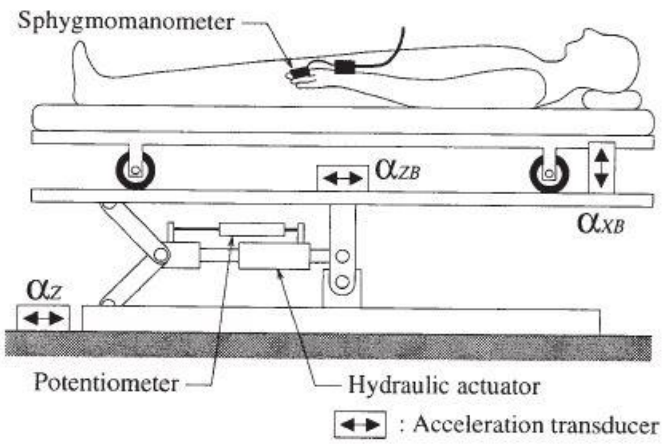
(g) As a basis of design for an automatic assembly or transfer machine.

Chapter 2
Literature review

Various researchers have tried to devised various mechanism for neutralizing the motions induced in the stretcher. Some of the researchers have tried to relate the effect of pitching motion on blood pressure variation. The study concluded that the blood pressure variation can be reduced by tilting the stretcher and counter balancing the inertia which arises due to braking of the vehicle. Others have tried to reduced peak acceleration acting on the stretcher by implementing passive damper system. Some of them have also tried to lessen the effects of pitch & roll by having the stretcher wall mounted and using counter weights as a balancing mechanism. . The case studies provide a brief explanation to why some of the designs may succeed to achieve one objective but fails at the other, hence, providing partial solution. This chapter is devoted to survey of literature relevant to the thesis and provide an overview of the literature on the historical development in reducing the effects of the motions acting on the stretcher

2.1 Literature Background

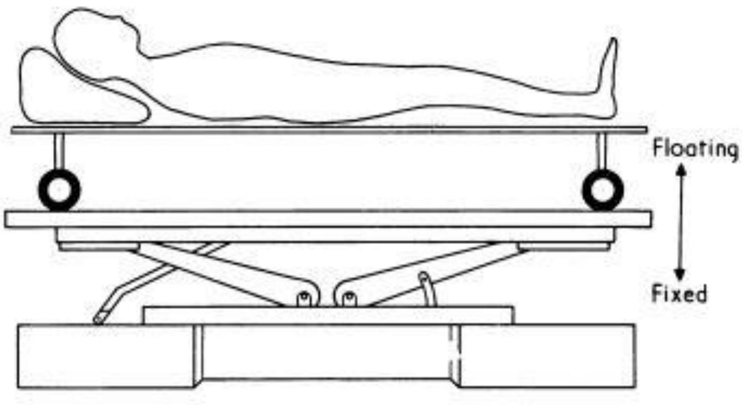
1. According to a study, published in, 'Proceedings of the Institution of Mechanical Engineers, Part H', conducted by K. Sagawa Et al.[3], design was suggested which succeeded in using pitch angle to stabilize the blood pressure of the patient.



2.1.1 Figure 1

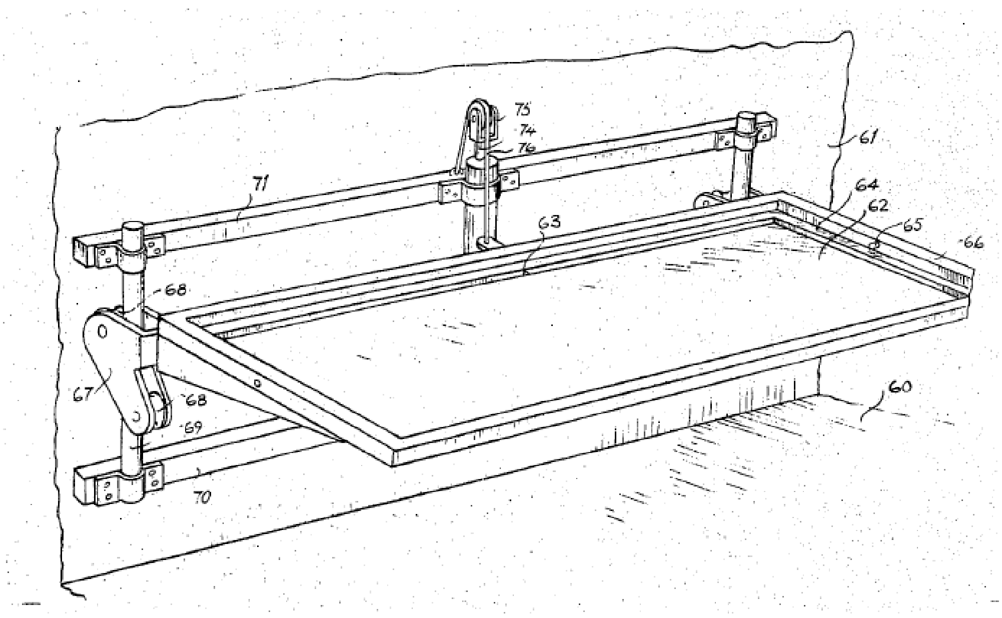
This study reflects upon the significance of the pitch angle on blood pressure variation thus, affecting human health.

2. According to a design of floating stretcher Snook Et al.[4] provided by, 'British Medical Journal, 1976, 2, 405-407', a reduction of 66% in peak acceleration value over a normal stretcher in range of 3 to 10 Hz was achieved. Although, no provisions are provided for compensation of pitch and roll.



2.1.2 Figure 2

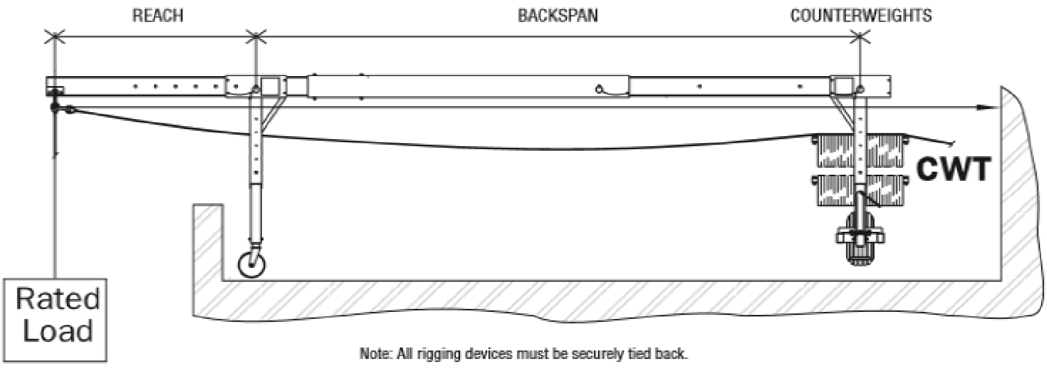
3. A patented design under United States Patent No. 3,840,265 by John Mowat Miller Stirling Et al.[5] a design of stretcher was suggested, which succeeded in balancing both pitching and rolling motion along with transverse movement.



2.1.3 Figure 3

The issue with this design is the weight of the entire patient in addition to that of the counter weight is supported by only four pivot points, hence, reducing the load carrying capacity. The mechanism requires to be mounted on wall of the ambulance, whereas, a Stewart Platform mechanism can be fixed on the floor. The significance of this fact comes into picture as side collisions are more frequent than rear and front end collisions Nadine Levick Et.al [6].

4. An idea published 'International Research Journal of Engineering and Technology, Volume 05, Issue 03' by Rinto K.Anto Et al. [7], in March, 2018, makes use of a counter-weight system in order to balance vibrations induced in stretcher but isn't much effective against pitching and rolling motion. It is a passive system which requires weight recalibrations for different patients.



2.1.4 Figure 4

2.2 Problem Definition

From the literature review it is clear that majority of the engineering solutions are provided for damping of the vibrations experienced by the stretcher and only a few took into account the effect of pitching and rolling motion. In the regions like Ghats where chaotic banking is a natural occurrence, many of the provided solutions may fail, as the movement of the stretcher is inline with the movement of the ambulance. This increases the blood pressure which will be responsible for more critical condition of the patient.

2.3 Objective

In order to keep the blood pressure of the patient normal the stretcher should remain in horizontal condition in case of road, air and water ambulances.

The main objective of this project is to construct a functioning prototype to balance the pitching and the rolling motion experienced by the base by providing counter orientation to the top platform; and the implementation of this prototype into working model.

The secondary objective is to provide a customised orientation to the top platform with respect to the base by means of controlling device.

2.4 Scope of the Present Work

Functionality of Gough-Stewart Platform and its applications is a particular interest of present work. This thesis mainly focuses on limiting the motion transferred to the stretcher by constraining its pitch and roll. This thesis will help to demonstrate the use of inverse kinematics for positioning of a platform parallel to the gravitational plane. The prototype so created can be implemented in emergency vehicles in order to provide comfort to the patient and ease of operation performed by the EMT staff. It can also prevent motion sickness experienced while travelling through Ghats. The reduction of motion also helps in situations when the patient is tracheotomized or is subjected to intravenous therapy.

Chapter 3
Design and Implementation

The chapter covers the parameters acquired by means of surveys, and their utilization in determining the constraints and henceforth, deciding the dimensions of the prototype. This chapter also constitute of various components employed in the making of the prototype and its bill of material.

3.1 Design Constraints

For the design of the prototype spatial constraints were calculated by conducting survey at a local medical facility. Note that the stretcher dimensions are not standardized and the value may change as per the surveyed emergency vehicle. The platform must be capable of achieving a minimum height so that the stretcher could be mounted above the platform. The stretcher measured had custom designed guideways to allow the foldable stretcher bend and slide through it. The distance between the bottom of the stretcher and the ambulance’s base defines the minimum height. The height so determined was 24 cm.

Secondly, the diameter of the platform used must lie within the volume constrained by the guideways. The stretcher width was measured as 55 cm. The top plate's diameter was taken as 35 cm.

3.1 'USI – 1008' Stretcher Model

The motors are placed at angle of $\pi/3$ radians to each other on a circular base as the cables provided were short to interconnect multiple motors in series.

The apparatus used in the setup were selected taking into consideration the availability and the cost of the products in the market.

The rotating element of the servo motor is 2.2 cm. Although, the motor can take high loads when connected to supply, the servo horns descend down from its home position when disconnected. This eliminates the usage of ball joints above M4, as it would increase both the weight of the ball joints and the rod connecting them. The usage of M3 was more suitable for the case.

As acrylic sheet provides an aesthetic appeal as well as good enough functionality for the prototype, it was opted for. In addition, it can be precisely cut using laser cutter with M3 holes to connect it with rotating element of motor.

3.2 Components list

Component	Quantity
Dynamixel AX-12A	6
Arduino Mega 2560	1
MPU6050	1
HC-05	1
IC 74LS241N	1
Threaded Rods	6
Ball Joints	12
Acrylic Sheet	2
Printed Circuit Board	1

Table 3.2: List of components

3.3 Component Details

1. Dynamixel AX-12A

The AX-12A servo actuator from 'Robotis' and it is the most advanced actuator on the market. The AX-12A robot servo has the ability to track its speed, temperature, shaft position, voltage, and load. Also, the control algorithm used to maintain shaft position on the ax-12 actuator can be adjusted individually for each servo, allowing you to control the speed and strength of the motor's response. All of the sensor management and position control is handled by the servo's built-in microcontroller.

Specifications:

1) Operating Voltage : 9-12V
2) Stall Torque : 15.3 kg.cm
3) Size : 32 × 50 × 40 mm
4) Resolution : 0.29°

5) No load speed : 59 rpm
6) Maximum current : 900 mA
7) Material : Plastic Gears and Body

3.3.1 Dynamixel AX-12A

The above motor was selected due to its high torque at smaller size for the constraints as per the survey of the ambulance.

2. Arduino Mega

The Mega 2560 is a microcontroller board based on the ATmega2560 processor. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Specifications:

1) Input voltage : 7-12 V
2) Operating voltage : 5 V
3) DC current per I/O pin : 20 mA
4) Clock speed : 16 MHz
5) Flash memory : 256 KB
6) Length : 101.52 mm
7) Width : 53.3 mm

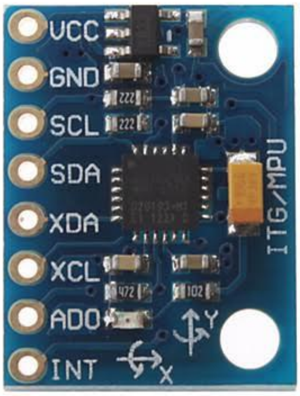
3.3.2 Arduino Mega 2560

3. MPU6050

The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor (DMP), which processes complex 6-axis motion fusion algorithms. The device can access external magnetometers or other sensors through an auxiliary master I²C bus, allowing the devices to gather a full set of sensor data without intervention from the system processor.

Specifications

1) Supply voltage : 5 V
2) Dimensions : 4 × 4 × 0.9 mm
3) Full scale range : ± 2000º/sec



3.3.3 MPU6050

4. HC-05

HC-05 module is an easy to use Bluetooth Serial Port Protocol (SPP) module, designed for transparent wireless serial connection setup. The HC-05 Bluetooth Module can be used in a Master or Slave configuration, making it a great solution for wireless communication. This serial port bluetooth module is fully qualified Bluetooth V2.0 + Enhanced Data Rate (EDR) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Rluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature).

The Bluetooth module HC-05 is a 'master/slave' module. By default, the factory setting is 'slave'. The Role of the module (Master or Slave) can be configured only by 'AT commands'. The slave modules cannot initiate a connection to another Bluetooth device, but can accept connections. Master module can initiate a connection to other devices.

Specifications

1) Operating voltage : 5 V
2) Operating current : 30 mA
3) RF transmission power : 4 dBm
4) Sensitivity : 80 dBm
5) Range : <100 m
6) Dimensions : 27 × 13 × 2 mm

3.3.4 HC-05

5. IC 74LS241N

Dynamixel AX-12A uses half duplex communication of 1Mbps which requires additional circuitry to make connections to Arduino, if there are several servos to be connected. A single servo can be connected directly to the Arduino but, in the case of several actuators it is necessary to use a tri-state buffer, which is placed between the Arduino and AX-12A. IC 74LS241N is a simple tri-state buffer, which is used for conversion of full duplex to half duplex.

Specifications

1) Operating voltage : 5V
2) Input current : 0.2 mA
3) Output current : 24 mA
4) Number of pins : 20
5) Dimensions : 26 × 8 × 7

3.3.5 IC 74LS241N

6. Acrylic Sheet

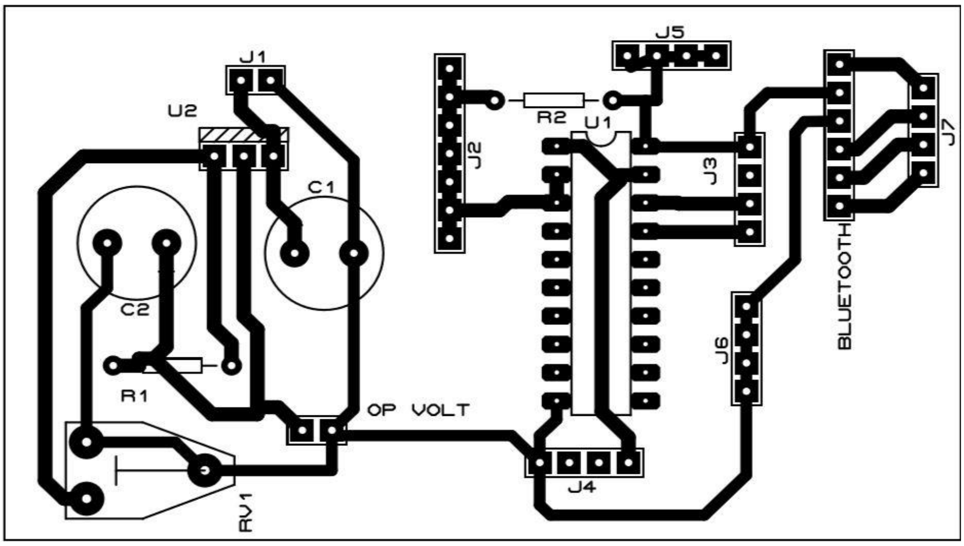
Acrylic sheet provides an aesthetic appeal as well as it has good functionality for the prototype. In addition, it can be precisely cut using laser cutter with M3 holes, as required, to connect it with rotating element of motor.

Survey of ambulance was conducted and it was found that the space available between the guide rails, for the stretcher, is nearly 38 cm. taking clearances into account, diameter of plate was selected as 35 cm. Thickness of top plate was selected as 4 mm by taking into consideration the effect of weight and bottom plate thickness was selected as 8 mm for providing rigid support

Specifications

1) Diameter (for both top and bottom plates) : 35 cm
2) Thickness (top plate) : 4 mm
3) Thickness (bottom plate) : 8 mm

7. Printed Circuit Board



3.3.6 PCB schematic

3.4 Implementation in an Actual Ambulance

The chapter takes into consideration the actual conditions that will be subjected to the system when it is employed in an actual ambulance. Parameters such as load carrying capacity will highly vary for the prototype and the functioning model, hence, certain modifications, for instance type of actuators utilised need to be made.

This chapter also decides the placement of the model beneath the stretcher, and simple solutions that can be put to use for mounting of the latter on the former.

3.5 Selection of Actuators

According to a research article by Sarah Catherine Walpole Et al.[8] published thru BioMed Central, average body mass of a typical Asian is 57.7 kg. Hence, actuators having a higher load carrying capacity needs to be made use of in order to bear such weight.

It shall also be taken into account, that these linear actuators must not be driven by hydraulic or pneumatic means, so, as to eliminate the use of hydraulic pumps or compressed air. This factor holds significance as space is an essential aspect to be considered in an emergency vehicle. Also, the downside to pneumatic actuator is that they are more susceptible to leakage, making them less efficient than mechanical linear actuators.

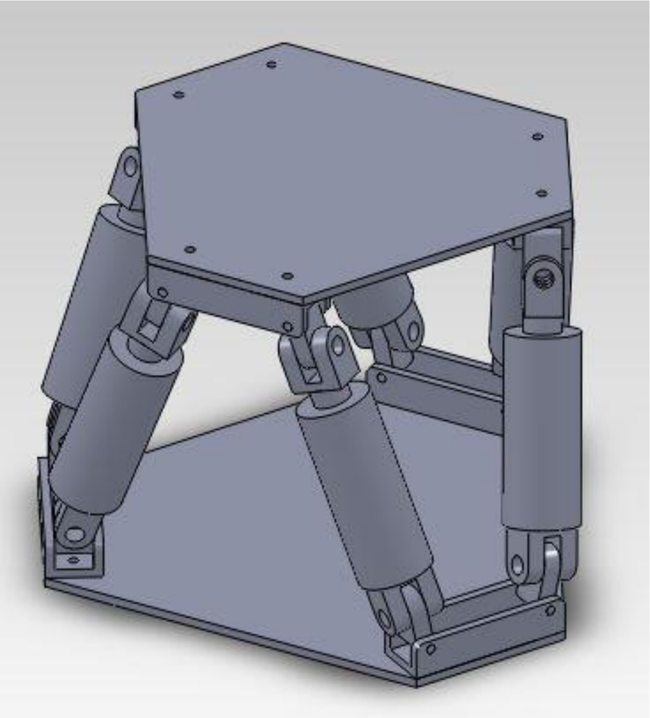
An example of mechanical linear actuator that can be used in construction of the actual model is 'PA-04' manufactured by 'Progressive Automations'. The actuator delivers a linear velocity of 2.16 inches / second at full load condition. It has a load carrying capacity above 100 lbs per actuator. The available stroke length for this actuator, in the market varies from 1 to 40 inches. The operational sound of the actuator is limited under 45 decibels.

Another actuator, 'PA-15' produced by the same manufacturer operates at a linear velocity of 2 inches / second at full load condition, with a load carrying capacity of 33 lbs per actuator. The stroke lengths available in market varies from 1 to 30 inches.

3.6 Modifications in Design

The prototype had the motors placed at an angle of $\pi/3$ radians apart from each other. But in actual case, the setup will be constructed according to figure 1 illustrated in chapter 1, under section 2.

The design will consist of six linear actuators, attached in pairs to three positions on the base, crossing over to three mounting points on a top plate. Let these mounting points be referred as 'A', 'B' and 'C', this will be important in next section. All 12 connections are made via universal joints. A desired orientation can be provided to the platform by varying the lengths of the linear actuators.



3.6 Design used in Actual Employed Model

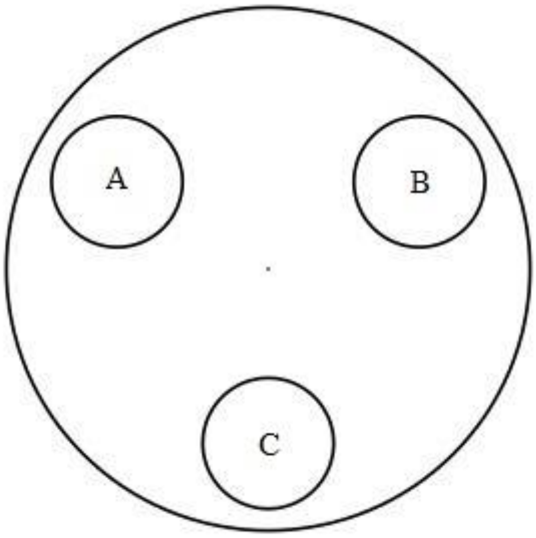
3.7 Orientation of The Platform under Stretcher

According to a study[9] conducted by Naval Biodynamics Laboratory in New Orleans, Louisiana, the mass distribution of human body segments for medium size person was recorded as follows.

Segment of Human Body	Mass in Kilograms
Head	4.2
Neck	1.1
Thorax	24.9
Abdomen	2.4
Pelvis	11.8
Upper Arm	2.0
Forearm	1.4
Hand	0.5
Thigh	9.8
Calf	3.8
Foot	1.0

Table 3.7: Mass Distribution of Human Body Segments

Although, the sample space consisted of military male aviators, the fact can be established that mass is more distributed towards the top of the human body. Thus, the constructed setup has to be placed such that any two of the mounting points defined in earlier section 2 of this chapter must be utilised to handle the top segment of the body.



3.7 Orientation of Stewart Platform under Stretcher

Absence of significant different in distribution of mass along the breadth, allows the platform to be placed on the longitudinal axis.

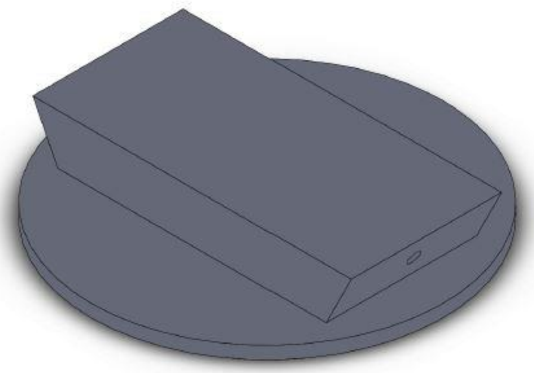
3.8 Mounting Accessories

The ambulance surveyed earlier in process of acquisition of spatial constraints had guide rails provided of the base. The stretcher, 'USI-1008', shown in figure 6 in chapter 3 under section 1 was employed for this case. When pushed against the ambulance the legs of the stretcher folds and tyres roll into the guide rails restricting the motion into a straight line.

Once the stretcher is placed in the ambulance Stewart Platform is required to lift the stretcher. Furthermore, the latter when lifted must not slide off the former when subjected to pitching or rolling motion. Hence, there is a necessity of development of a mounting device to hold stretcher tightly on the platform. A number of engineering solutions for mounting mechanism can be implemented for this application. One such simple mounting mechanism could be as follows,

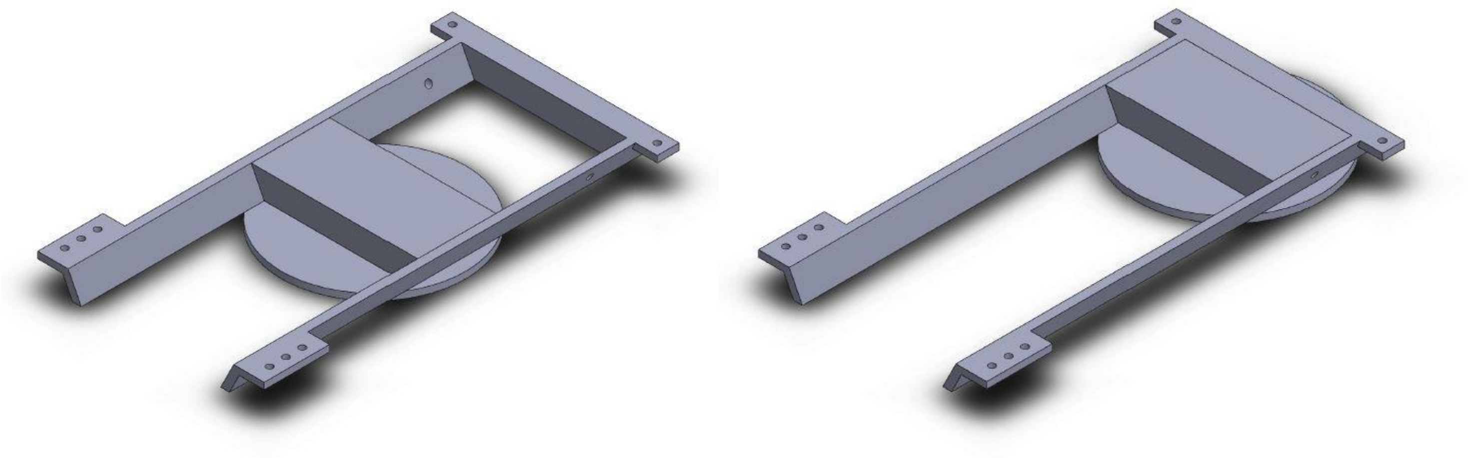
3.8.1 Suggested Design for Guideway

A guideway can be mounted below the stretcher, such that the counter profile provided on the top of Stewart Platform can slide through it when the stretcher is pushed inside the ambulance.



3.8.2 Suggested Design for Top Platform

This arrangement restricts all motions of stretcher with respect to top platform except for the required sliding of former, when it is loaded or unloaded from the ambulance. Provision is also made to restrict this movement by means



of a rod that can be inserted inside the hole drilled all the way through the setup.

3.8.3 Mounting Procedure

Many other available engineering solution can be implemented in mounting of the stretcher with varying range of complexities. The mounting mechanism mentioned earlier is solely suggestion for modification in the stretcher model ‘USI-1008’. New enhanced mechanism can be employed in stretchers of different models, based on the available information resources.

Chapter 4
Calculations and Algorithm

The chapter deals with identification and formulation of certain variables which play a significant role in determining the angle of rotation to be provided to the servo horn in order to position the top platform at a defined orientation with respect to the base plate. These calculations also help in determining the link length that connects the servo horn to top plate, taking into account the spatial constraints. Various matrices derived under this chapter will later be employed in coding of the microcontroller.

5.1 Determination of Link Length

Let,

s = length of the link form the center of the two connected ball joints

l = distance between center of servo motor axis and corresponding point on platform

a = length of the servo horn

α = angle of the servo horn to the horizontal plane

Assuming, $\alpha = 0$, as the default position for all the motors,

Therefore, by using Pythagoras Theorem,

$s^2 = l^2 + a^2$

Considering, thickness of the base plate and the socket provided for attaching motor plus the height up to motor axis along with some clearances, the value of l for default position comes out to be 17.291 cm.

$s^2 = 17.291^2 + 5^2$

$s = 18$ cm

5.2 Formulation of Angle of Servo Horn

All the points are defined with respect to an origin located on the bottom centre of the base plate.

Point on the platforms are defined as (X_p, Y_p, Z_p).

Point on the axis of the motor are defined as (X_b, Y_b, Z_b).

Point on the connecting point of servo arm and links are defined as (X_a, Y_a, Z_a).

$X_a = X_b – (-1)^n . a . \cos(\alpha) . \sin((n-1) . \frac{\pi}{3})$ …(1)

$Y_a = Y_b + (-1)^n . a . \cos(\alpha) . \cos((n-1) . \frac{\pi}{3})$ …(2)

$Z_a = Z_b + a . \sin(\alpha)$ …(3)

$a^2 = (X_a – X_b)^2 + (Y_a – Y_b)^2 + (Z_a - Z_b)^2$ …(4)

$l^2 = (X_p – X_b)^2 + (Y_p – Y_b)^2 + (Z_p - Z_b)^2$ …(5)

$s^2 = (X_p – X_a)^2 + (Y_p – Y_a)^2 + (Z_p – Z_a)^2$ …(6)

Substituting equations (4) and (5) in equation (6) and rearranging gives,

$l^2 – (s^2 – a^2) = 2(X_b^2 + Y_b^2 + Z_b^2) + 2X_a . (X_p – X_b) + 2Y_a . (Y_p – Y_b) + 2Z_a . (Z_p – Z_b) + 2(X_p X_b + Y_p Y_b + Z_p Z_b)$

Substituting values of X_a, Y_a and Z_a in the above equation gives,

$l^2 – (s^2 – a^2) = 2(X_b^2 + Y_b^2 + Z_b^2) + 2(X_b – (-1)^n . a . \cos(\alpha) . \sin((n-1) . \frac{\pi}{3})) . (X_p – X_b) + 2(Y_b + (-1)^n . a . \cos(\alpha) . \cos((n-1) . \frac{\pi}{3})). (Y_p – Y_b) + 2(Z_b + a . \sin(\alpha)) . (Z_p – Z_b) + 2(X_p X_b + Y_p Y_b + Z_p Z_b)$

Further, rearrangement and reduction of the above equation is done to the following form,

$\underline{l^2 – (s^2 – a^2)} = \underline{(2. a . (Z_p – Z_b))} . \sin(\alpha) + \underline{((2 . (-1)^n . a) . ((Y_p – Y_b) . \cos((n-1) . \frac{\pi}{3}) - (X_p – X_b) . \sin((n-1) . \frac{\pi}{3})))} . \cos(\alpha)$

The above equation is in the form,

$L = M \sin(\alpha) + N\cos(\alpha)$

We therefore have another sine function of α with a phase shift δ,

$L = (M^2 + N^2)^{1/2} . \sin(\alpha + \delta)$

Where,

$\delta = \tan^{-1} (M/N)$

Therefore,

$\alpha = \sin^{-1}(L/(M^2 + N^2)^{1/2}) - \tan^{-1}(N/M)$

Where,

$L = l^2 - (s^2 - a^2)$

$M = (2 . a . (Z_p - Z_b))$

$N = ((2 . (-1)^n . a) . ((Y_p - Y_b) . \cos((n-1) . \frac{\pi}{3}) - (X_p - X_b) . \sin((n-1) . \frac{\pi}{3})))$

5.3 Construction of Matrices

The yawing motion of the stretcher is constrained by the walls of the ambulance hence is not considered.

${}^{p}\mathbb{R}_{b\text{-}x}$ = Rotation of platform with respect to base about x axis and takes care of the pitching motion of the platform.

${}^{p}\mathbb{R}_{b\text{-}y}$ = Rotation of platform with respect to base about y axis and takes care of the rolling motion of the platform.

$${}^{p}\mathbb{R}_{b\text{-}x} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(x) & \sin(x) \\ 0 & -\sin(x) & \cos(x) \end{bmatrix}$$

$${}^{p}\mathbb{R}_{b\text{-}y} = \begin{bmatrix} \cos(y) & 0 & -\sin(y) \\ 0 & 1 & 0 \\ \sin(y) & 0 & \cos(y) \end{bmatrix}$$

${}^{p}\mathbb{R}_{b} = {}^{p}\mathbb{R}_{b\text{-}y} . {}^{p}\mathbb{R}_{b\text{-}x}$

$${}^{p}\mathbb{R}_{b} = \begin{bmatrix} \cos(y) & -\sin(x) * \sin(y) & -\cos(x) * \sin(y) \\ 0 & \cos(x) & \sin(x) \\ -\sin(y) & -\sin(x) * \cos(y) & \cos(x) * \cos(y) \end{bmatrix}$$

Where,

x = Pitching angle

y = Rolling angle

$$
{}^{b}\mathbb{R}_{p} = \begin{bmatrix} \cos(y) & 0 & -\sin(y) \\ -\sin(x) * \sin(y) & \cos(x) & -\sin(x) * \cos(y) \\ -\cos(x) * \sin(y) & \sin(x) & \cos(x) * \cos(y) \end{bmatrix}
$$

The subscript ‘b’ does not denote the base of the setup but the plane consisting the centre points of the rotating element of the motors. From here on it will be referred as false base.

The false base is located at a height of 4.65 cm above the true base. The rotation of the true base can result in translation in the false base. This translation can be denoted by the following matrix.

$$
T = \begin{bmatrix} 4.65 * \sin(x) \\ 4.65 * \sin(y) \\ 0 \end{bmatrix}
$$

5.4 Functioning and Algorithm of Prototype

The chapter explains a detailed working of both the primary objective of providing counter orientation to the top platform according to the data provided by the base as well as the secondary objective of providing a custom orientation to the top platform with respect to the base by means of a controlling device by means of Bluetooth.

5.5 Self-Balancing Platform

All six centre points of the rotating element of the motors located on the false base are to be defined with respect to origin. Similar procedure is employed for the identification of the consecutive six points on the top platform.

When the true base is subjected to motion, the corresponding values of angle of pitch and roll and received from a gyroscopic chip, ‘MPU-6050’. This helps determining the translation of the false base with respect to the true base.

The platform points are considered constant and rotation of base with respect to platform is found. This can be determined by multiplying individual coordinates of base with ${}^{b}\mathbb{R}_{p}$. The translation matrix is then added to the rotated coordinates and new orientation of the base is found.

$$[P_{new}]_{1x3} = [P_{defined}]_{1x3} * [{}^{b}\mathbb{R}_{p}]_{3x3} - [T]_{1x3}$$

Using equation number (5) from section (ii) of chapter 5, the corresponding value of ‘l’ can be found for any point B_{new} and its corresponding pair on the platform. Similar procedure is repeated for all remaining five pairs.

The relationship derived earlier between the servo angle and ‘l’ can be then used to determine how much rotation is to be provided to the servo horn.

5.6 Manual Control over Orientation

Provision is provided to toggle between the self-balancing mode and manual controlling mode. A Bluetooth chip, ‘HC-05’ is employed to transmit signals from a controller to Arduino Mega 2560. The signals are in the form of ASCII codes with a specified function allotted to selected alphabets.

The values of pitching and rolling angles are modified according to the signals received. In addition, provision for altering translation along the transverse direction are also provided. Unlike the self-balancing mode, the platform points are not considered constant but the false base is considered stationary. Hence, new points of the platform are found by the following equation,

$$[P_{new}]_{1x3} = [P_{defined}]_{1x3} * [{}^{p}\mathbb{R}_{b}]_{3x3} + [{}^{p}T_{b}]_{1x3}$$

The remaining procedure of determination of angle of rotation to be provided to the servo horn remains same as in that of the self-balancing mode.

5.7 C / C++ Code

```
//CGS
#include <Wire.h>
#include <DynamixelSerial1.h>

//Radius of base plate = 17.75cm
const float b1[3] = {17.75,0,4.65};
const float b2[3] = {8.875,15.371,4.65};
const float b3[3] = {-8.875,15.371,4.65};
const float b4[3] = {-17.75,0,4.65};
const float b5[3] = {-8.875,-15.371,4.65};
const float b6[3] = {8.875,-15.375,4.65};

//Radius of top plate = 18cm
const float p1[3] = {18,0,21.941};
const float p2[3] = {9,15.588,21.941};
const float p3[3] = {-9,15.588,21.941};
const float p4[3] = {-18,0,21.941};
```

```
const float p5[3] = {-9,-15.588,21.941};
const float p6[3] = {9,-15.588,21.941};

float pn1[3];
float pn2[3];
float pn3[3];
float pn4[3];
float pn5[3];
float pn6[3];

const int MPU_addr = 0x68;
int16_t AcX,AcY,AcZ;

int minVal = 265;
int maxVal = 402;

int data = 0;

double x,y,z;

float rttn[3][3];
float t[3] = {0,0,0};

float correction_x = 4; //Correction in pitch in degrees
float correction_y = 0; //Correction in roll in degrees
float correction_z = 0; //Correction in yaw in degrees

float rad = 1.591 * DEG_TO_RAD;

float PTCH = 0;
float RLL = 0;

bool flag = true;
bool hm = false;
////////////////////////////////////////////////////////////////////////////////
float distance (float p[3], float rotate[3][3], float translate[3], float
p_new[3], float base[3]) {
float ans = 0;
```

```
int i,j;

//Rotation
for(i=0;i<3;i++) {
p_new[i] = 0;
for(j=0;j<3;j++)
p_new[i] += p[j] * rotate[j][i];
}

//Translation
for(i=0;i<3;i++)
p_new[i] -= translate[i];

for(i=0; i<3; i++)
ans += pow((p_new[i] - base[i]),2);
return sqrt(ans);
}
////////////////////////////////////////////////////////////////////////////////////
void setup() {
Serial.begin(115200);
Serial2.begin(9600);

Dynamixel.begin(1000000,2);
Dynamixel.setMaxTorque(254,640);

Wire.begin();
Wire.beginTransmission(MPU_addr);
Wire.write(0x6B);
Wire.write(0);
Wire.endTransmission(true);
}
////////////////////////////////////////////////////////////////////////////////////
void loop() {
float l1,l2,l3,l4,l5,l6;
float L1,L2,L3,L4,L5,L6;
float M1,M2,M3,M4,M5,M6;
float N1,N2,N3,N4,N5,N6;
```

```
float lf1,lf2,lf3,lf4,lf5,lf6;

if(Serial2.available() > 0) {
data = Serial2.read();

if(data == 78) {
flag = false;
hm = false;
}

if(data == 70)
flag = true;
}

if(flag == false) {

if(hm == false) {
Dynamixel.move(254,512);
delay(50);
hm = true;
lf1 = 0;
lf2 = 0;
lf3 = 0;
lf4 = 0;
lf5 = 0;
lf6 = 0;
}

if(Serial2.available() > 0) {
data = Serial2.read();

switch(data) {
  case 80   : PTCH += rad;
              break;
  case 112  : PTCH -= rad;
              break;
  case 82   : RLL += rad;
```

```
            break;
  case 114  : RLL -= rad;
            break;
  case 84   : t[2] -= 0.5;
            break;
  case 116  : t[2] += 0.5;
            break;
  case 72   : Dynamixel.move(254,512);
            PTCH = 0;
            RLL = 0;

            lf1 = 0;
            lf2 = 0;
            lf3 = 0;
            lf4 = 0;
            lf5 = 0;
            lf6 = 0;

            t[2] = 0;
            break;
}
}

rttn[0][0] =   cos(-RLL);
rttn[0][1] =   sin(-RLL) * sin(PTCH);
rttn[0][2] = - sin(-RLL) * cos(PTCH);
rttn[1][0] =   0;
rttn[1][1] =   cos(PTCH);
rttn[1][2] =   sin(PTCH);
rttn[2][0] =   sin(-RLL);
rttn[2][1] = - cos(-RLL) * sin(PTCH);
rttn[2][2] =   cos(-RLL) * cos(PTCH);

l1 = distance(p1,rttn,t,pn1,b1);
l2 = distance(p2,rttn,t,pn2,b2);
l3 = distance(p3,rttn,t,pn3,b3);
l4 = distance(p4,rttn,t,pn4,b4);
```

```
l5 = distance(p5,rttn,t,pn5,b5);
l6 = distance(p6,rttn,t,pn6,b6);

L1 = pow(l1,2) - 299;
L2 = pow(l2,2) - 299;
L3 = pow(l3,2) - 299;
L4 = pow(l4,2) - 299;
L5 = pow(l5,2) - 299;
L6 = pow(l6,2) - 299;

M1 = 10*(pn1[2]-b1[2]);
M2 = 10*(pn2[2]-b2[2]);
M3 = 10*(pn3[2]-b3[2]);
M4 = 10*(pn4[2]-b4[2]);
M5 = 10*(pn5[2]-b5[2]);
M6 = 10*(pn6[2]-b6[2]);

N1 =  -10*(cos(0)      *(pn1[1]-b1[1]) - sin(0)      *(pn1[0]-b1[0]));
N2 =   10*(cos(PI/3)   *(pn2[1]-b2[1]) - sin(PI/3)   *(pn2[0]-b2[0]));
N3 =  -10*(cos(2*PI/3) *(pn3[1]-b3[1]) - sin(2*PI/3) *(pn3[0]-b3[0]));
N4 =   10*(cos(PI)     *(pn4[1]-b4[1]) - sin(PI)     *(pn4[0]-b4[0]));
N5 =  -10*(cos(4*PI/3) *(pn5[1]-b5[1]) - sin(4*PI/3) *(pn5[0]-b5[0]));
N6 =   10*(cos(5*PI/3) *(pn6[1]-b6[1]) - sin(5*PI/3) *(pn6[0]-b6[0]));

//lf is the angle alfa with 2.844 as convertion factor from degrees to domain of 0
- 1023.
lf1 += (asin(L1/sqrt(pow(M1,2)+pow(N1,2)))-atan(N1/M1)) * RAD_TO_DEG * 2.844;
lf2 += (asin(L2/sqrt(pow(M2,2)+pow(N2,2)))-atan(N2/M2)) * RAD_TO_DEG * 2.844;
lf3 += (asin(L3/sqrt(pow(M3,2)+pow(N3,2)))-atan(N3/M3)) * RAD_TO_DEG * 2.844;
lf4 += (asin(L4/sqrt(pow(M4,2)+pow(N4,2)))-atan(N4/M4)) * RAD_TO_DEG * 2.844;
lf5 += (asin(L5/sqrt(pow(M5,2)+pow(N5,2)))-atan(N5/M5)) * RAD_TO_DEG * 2.844;
lf6 += (asin(L6/sqrt(pow(M6,2)+pow(N6,2)))-atan(N6/M6)) * RAD_TO_DEG * 2.844;

if(L1/sqrt(pow(M1,2)+pow(N1,2)) >= (-1) && L1/sqrt(pow(M1,2)+pow(N1,2)) <= 1)
Dynamixel.move(1,(512-lf1));
delay(50);
if(L2/sqrt(pow(M2,2)+pow(N2,2)) >= (-1) && L2/sqrt(pow(M2,2)+pow(N2,2)) <= 1)
Dynamixel.move(2,(512+lf2));
```

```
delay(50);
if(L3/sqrt(pow(M3,2)+pow(N3,2)) >= (-1) && L3/sqrt(pow(M3,2)+pow(N3,2)) <= 1)
Dynamixel.move(3,(512-lf3));
delay(50);
if(L4/sqrt(pow(M4,2)+pow(N4,2)) >= (-1) && L4/sqrt(pow(M4,2)+pow(N4,2)) <= 1)
Dynamixel.move(4,(512+lf4));
delay(50);
if(L5/sqrt(pow(M5,2)+pow(N5,2)) >= (-1) && L5/sqrt(pow(M5,2)+pow(N5,2)) <= 1)
Dynamixel.move(5,(512-lf5));
delay(50);
if(L6/sqrt(pow(M6,2)+pow(N6,2)) >= (-1) && L6/sqrt(pow(M6,2)+pow(N6,2)) <= 1)
Dynamixel.move(6,(512+lf6));
delay(50);
}

if(flag == true) {
Wire.beginTransmission(MPU_addr);
Wire.write(0x3B);
Wire.endTransmission(false);
Wire.requestFrom(MPU_addr,14,true);

AcX=Wire.read()<<8|Wire.read();
AcY=Wire.read()<<8|Wire.read();
AcZ=Wire.read()<<8|Wire.read();

int xAng = map(AcX,minVal,maxVal,-90,90);
int yAng = map(AcY,minVal,maxVal,-90,90);
int zAng = map(AcZ,minVal,maxVal,-90,90);

x=   (atan2(-yAng, -zAng)+PI) + correction_x * DEG_TO_RAD;
y= - (atan2(-xAng, -zAng)+PI) + correction_y * DEG_TO_RAD;
z=   (atan2(-yAng, -xAng)+PI) + correction_z * DEG_TO_RAD;

//x, y values are fed by MPU6050.
rttn[0][0] =   cos(y);
rttn[0][1] =   0;
rttn[0][2] =   sin(y);
```

```
rttn[1][0] =   sin(y) * sin(x);
rttn[1][1] =   cos(x);
rttn[1][2] = - cos(y) * sin(x);
rttn[2][0] = - sin(y) * cos(x);
rttn[2][1] =   sin(x);
rttn[2][2] =   cos(y) * cos(x);

t[0] = 4.65*sin(x);
t[1] = 4.65*sin(-y);
t[2] = 0;

l1 = distance(p1,rttn,t,pn1,b1);
l2 = distance(p2,rttn,t,pn2,b2);
l3 = distance(p3,rttn,t,pn3,b3);
l4 = distance(p4,rttn,t,pn4,b4);
l5 = distance(p5,rttn,t,pn5,b5);
l6 = distance(p6,rttn,t,pn6,b6);

L1 = pow(l1,2) - 299;
L2 = pow(l2,2) - 299;
L3 = pow(l3,2) - 299;
L4 = pow(l4,2) - 299;
L5 = pow(l5,2) - 299;
L6 = pow(l6,2) - 299;

M1 = 10*(pn1[2]-b1[2]);
M2 = 10*(pn2[2]-b2[2]);
M3 = 10*(pn3[2]-b3[2]);
M4 = 10*(pn4[2]-b4[2]);
M5 = 10*(pn5[2]-b5[2]);
M6 = 10*(pn6[2]-b6[2]);

N1 =  -10*(cos(0)      *(pn1[1]-b1[1]) - sin(0)      *(pn1[0]-b1[0]));
N2 =   10*(cos(PI/3)   *(pn2[1]-b2[1]) - sin(PI/3)   *(pn2[0]-b2[0]));
N3 =  -10*(cos(2*PI/3) *(pn3[1]-b3[1]) - sin(2*PI/3) *(pn3[0]-b3[0]));
N4 =   10*(cos(PI)     *(pn4[1]-b4[1]) - sin(PI)     *(pn4[0]-b4[0]));
N5 =  -10*(cos(4*PI/3) *(pn5[1]-b5[1]) - sin(4*PI/3) *(pn5[0]-b5[0]));
```

```
N6 =   10*(cos(5*PI/3) *(pn6[1]-b6[1]) - sin(5*PI/3) *(pn6[0]-b6[0]));



lf1 = (asin(L1/sqrt(pow(M1,2)+pow(N1,2)))-atan(N1/M1)) * RAD_TO_DEG * 2.844;
lf2 = (asin(L2/sqrt(pow(M2,2)+pow(N2,2)))-atan(N2/M2)) * RAD_TO_DEG * 2.844;
lf3 = (asin(L3/sqrt(pow(M3,2)+pow(N3,2)))-atan(N3/M3)) * RAD_TO_DEG * 2.844;
lf4 = (asin(L4/sqrt(pow(M4,2)+pow(N4,2)))-atan(N4/M4)) * RAD_TO_DEG * 2.844;
lf5 = (asin(L5/sqrt(pow(M5,2)+pow(N5,2)))-atan(N5/M5)) * RAD_TO_DEG * 2.844;
lf6 = (asin(L6/sqrt(pow(M6,2)+pow(N6,2)))-atan(N6/M6)) * RAD_TO_DEG * 2.844;

if(L1/sqrt(pow(M1,2)+pow(N1,2)) >= (-1) && L1/sqrt(pow(M1,2)+pow(N1,2)) <= 1)
Dynamixel.move(1,(512-lf1));

if(L2/sqrt(pow(M2,2)+pow(N2,2)) >= (-1) && L2/sqrt(pow(M2,2)+pow(N2,2)) <= 1)
Dynamixel.move(2,(512+lf2));

if(L3/sqrt(pow(M3,2)+pow(N3,2)) >= (-1) && L3/sqrt(pow(M3,2)+pow(N3,2)) <= 1)
Dynamixel.move(3,(512-lf3));

if(L4/sqrt(pow(M4,2)+pow(N4,2)) >= (-1) && L4/sqrt(pow(M4,2)+pow(N4,2)) <= 1)
Dynamixel.move(4,(512+lf4));

if(L5/sqrt(pow(M5,2)+pow(N5,2)) >= (-1) && L5/sqrt(pow(M5,2)+pow(N5,2)) <= 1)
Dynamixel.move(5,(512-lf5));

if(L6/sqrt(pow(M6,2)+pow(N6,2)) >= (-1) && L6/sqrt(pow(M6,2)+pow(N6,2)) <= 1)
Dynamixel.move(6,(512+lf6));
}
}
```

Chapter 5
Conclusion

The study concludes Gough-Stewart Platform can be implemented countering the pitching and the rolling action experienced by the stretcher positioned on the top platform while journey on banked & slopy roads. This is achieved by taking the readings of MPU-6050 and giving the counter orientation to the axis of the motor and providing translation correction for the base of Stewart platform.

The actuator used was selected as Dynamixel due to its high torque at small form factor. The Arduino was selected for the convenience of the programming to be done in C. The IC chip is used as full to half duplex converter which is necessary for handshaking of actuator and controller. The gyroscopic sensor was selected for its higher range and sensitivity over other solutions available. The circular shape of top and base was selected to maintain good stability for the base and for easy mounting solutions in the actual model considering the stretcher used.

Thus, facilitating a reduction in health complications is achieved by maintaining the blood pressure under control, since it is major factor experienced by the patients and enhancing the success rate of procedure on sight by making it easier for the EMT staff to handle critical medical situations.

5.1 Scope for Future

The setup can be used in conjunction with engineering systems specialised to deal with the vibration transmitted to the stretcher.

(a) It can be used in Water Ambulances for neutralising the effects of pitching which may lead to blood pressure variation.

(b) It can be used in Air Ambulances for reducing the effects of forces experienced during turbulence.

(c) As a support for a helicopter which is capable of being driven by the pilot, random actions being applied to the supporting platform as prescribed.

(d) As a basis of design for a Vibration Isolator in Museum.

Chapter 6
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