Smart Terrain Adaptive Robotic Suspension System (S.T.A.R.S.S)

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Abstract - *The present study is a proposition of a novel suspension system that is intended to be of great use in the field of autonomous or manned exploration primarily on extra-terrestrial planets. This new approach to suspension systems is fully electronic and uses negative feedback to stabilize the chassis. This research article attempts to let the reader go through the design process for the whole suspension system, including link design, dimensioning, electronic component selection, and finally, the embedded C code to attain the desired result. The reasons for choosing these parameters are well addressed in the work. Multiple tests were performed on a prototype that was built during this project on a track that simulated undulating surfaces for the robot to move on. Kinematic and structural analyses were carried out to ensure the prototype could perform as desired. These tests were constantly monitored using the open-source software, Processing, which gave real-time readings for the attitude of the chassis. The chassis model was drawn on OpenGL for easy visualization of the rolling, pitching, and yawing of the chassis. Multiple tests resulting in lots of code tweaks have ultimately resulted in the fulfillment of the objective.*

Key Words: Active suspension, horizontal chassis, links, electronics, cost-effective, etc.

1. INTRODUCTION

With planetary exploration becoming a major aim of all the Superpowers in the world, newer innovative and effective designs are wanted to travel on unknown terrains with safety assured. Unseen and unexplored terrains pose a great threat to vehicles movement and its components. Many designs are currently being researched upon and many simple yet very effective solutions like the "Rocker-Bogie Mechanism"[10][12] have surpassed all complications and have become the almost ideal solution for planetary exploration. Despite such mechanisms, there still exists the dream of fluid-like movement on rough terrains at a comparatively lower expense. We have decided to go with an independent, centrally controlled suspension system that relies on individual movements of the wheels to avoid roll instability. A centrally controlled suspension means that the "brain", that is, the microcontroller installed, controls the movements of the wheels depending upon the input parameters. We plan to introduce a simple yet cutting-edge robotic suspension system that can be made by modifying a 4 bar link mechanism to maintain a nearly horizontal chassis over considerable forms of undulating terrains. The suspension movement is controlled by an IMU (Inertial Measurement Unit) which relays attitude information to the microcontroller which processes this data and relays instructions to the system of servo motors, which helps in controlling and moving the link mechanism to attain a perfectly horizontal chassis. In addition to extraterrestrial expeditions, there has been a surge in military, energy production projects which demand a suspension system that is not sophisticated but at the same time, effective. With the help of electronics and simple mechanics, smarter, lighter, effective, and economical solutions for a larger spectrum of systems can be achieved.

1.1 Background

A suspension system is a link between the wheels and the body of a vehicle. It may comprise shock absorbers, springs, and linkages, all arranged in diverse ways depending on the purpose they are being utilized for. Over the past decades, numerous and distinctive changes have been made and advanced technologies keep coming through. Most of the suspension systems succeed and fulfill the objective they have been proposed for but there aren't as many mechanisms that guarantee an unwavering chassis. With modern developments in warfare, space explorations, and automobiles, such a mechanism is much needed. After much research and analysis, we have come forth with a system that applies the fundamentals of mechatronics to remotely control a vehicle's suspension. Unlike the current market leaders such as the MR fluid[1], pneumatics, and hydraulic-based systems, this one would function with the use of microcontrollers, gyroscopes, and accelerometers. It would sense data from its surroundings and then with the help of a series of programs, reciprocate and allow the body to be stable. Such a system, when implemented on a larger scale could prove to be very pragmatic.

1.2 Problem Statement

An ideal suspension system would be the one that is the most efficient and relatively cheaper. When working on a project, the first thing to keep in mind is the cost which is to be kept minimal without hampering its effectiveness.

To cope up we've come up with the mechanism that we aim to achieve would be feasible to build at a reasonable expense and produce more effective results.

1.3 Objectives

1. Stabilizes the chassis to make it almost horizontal, with a very small degree of error.
2. Enhance efficiency.
3. The robot must be able to go over both smooth undulating surfaces and sharp obstacles.
4. Cut down the maintenance-related.
5. For more load transfer & response.

1.4 Scope of project

The new suspension system can be a real breakthrough in the field of robotic suspension systems. It would be a modification and an improvement on previously existing suspension systems and hence be more effective. The suspension will help improve mobility on difficult terrains for military and space exploration activities. This suspension system can be implemented on various kinds of wheeled bots like the ones which have robotic arms or other modifications and can result in an even more versatile robot vehicle. Considering our project's deliverables, it can be an upgrade as compared to previous systems. The use of mechanical links as well as an automated system is something that has not been explored to the utmost and it could lead to further developments in the proposed field. The coding of the program and obtaining the best materials to maximize the potential of this study is a hurdle but it can be overcome with apropos research and discussions.

2. LITERATURE REVIEW

An innovation in any field requires a proper study of existing technologies which is why a major portion of the time of this project was dedicated to the literature survey. This helped us in understanding various current technologies, their precision, advantages, and disadvantages. The following table is a list of relevant published, patented, and unpublished research around the world.

Sr No.	Title	Relevance
1.	Yuxin Zhanga, Xinjie Zhanga, Min Zhana, Konghui Guoa, Fuquan Zhaoc, Zongwei Liu- ***Study on a novel hydraulic pumping regenerative suspension for vehicles***	Hydraulic actuators were chosen to absorb shock. But ruled out due to its cost
2.	BMW- ***Dynamic Drive***	Employs the use of sensors to detect the movement of wheels and creates counter forces. Ruled out because of cost.
3.	Karl Iagnemma, Adam Rzepniewski and Steven Dubowsky - ***Control of Robotic Vehicles with Actively Articulated Suspensions in Rough Terrain***	A new mechanism to overcome roll stability has made us think about a simple approach.
4.	Kazuo Tani, Osamu Matsumoto, Shuuji Kajita, Nobumasa Shirai-***Wheeled Robots to Overcome Ground Unevenness in Construction Areas***	A multi-functioning bot with 3 different mechanisms has made us think over a mechanism that can perform multiple tasks including climbing stairs
5.	Adibi Asl, H., Rideout, G- ***Using lead vehicle response to generate preview functions for active suspension of convoy vehicles***	A similar approach to Panshuo Li et al [6]. Except a whole convoy was mathematically modeled and deflections in tire of one were reading for the other. Can be implemented when we use COBOTS or swarms.
6.	Panshuo Li, James Lam, Kie Chung Cheung- ***Multi-objective control for active vehicle suspension with wheelbase preview [3]***	Front-wheel movements were used as inputs to stabilize. This gives us the ability to add pseudo wheels whose movements we can track

Table -1: Tabulated findings from relevant research around the world

Conclusions from Literature Survey

•There are 2 kinds of suspension systems - active and passive. While passive suspension systems are purely mechanical, active suspension systems are interfaced with plenty of sensors and electronics for higher precision. Since our suspension system has a lot of electronics involved (for higher accuracy), it falls under active suspension systems.

- Most of the active suspension systems are very expensive and require a lot of processing power. The suspension systems involving hydraulics, pneumatics, and linear actuators are very expensive as the components are very costly.

- Purely kinematic-based suspension systems are not precise enough, therefore a controlled kinematic suspension system would be perfect.

- The current near-perfect solutions like the BMW's dynamic drive[2] work well for really small vibrations and bumps. The suspension systems which can overcome large bumps are not precise enough which gives us our problem statement. We need to come up with a high-precision system that can overcome large bumps.

- The suspension system must have "auto-stabilization"[3] which means it must be able to recover from all sorts of unprecedented actuations due to rough terrain.

3. METHODOLOGY

We began by choosing an appropriate design for the link mechanism[4]. Some of the mechanisms that were prominent after discussions were –

- ○ A laid-back bent link 1 degree of freedom arm [Fig. 1(a)]
- ○ Three tire chain supported wheel [Fig. 1(b)]
- ○ Modified parallel four-bar linkage [Fig. 1(c)]

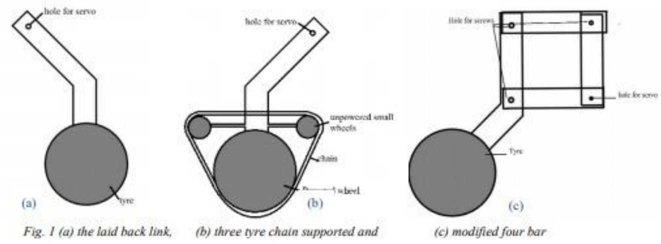

Fig -1: Types of Links

We started by analyzing various suspension systems that are currently used following which a detailed study of the evolution of suspension mechanisms was done to know how each of them worked.

The basic working principle of each system was studied individually followed by the analysis of the flaws in each of them. After discussion, we came up with a modified parallel four-bar link mechanism. Then moved on to the simulation of our model in the SOLIDWORKS software followed by ANSYS. After this step, the Electronic components were chosen and the microcontroller was interfaced with the IMU and servos. Primitive algorithms and codes were written and tested with suitable modifications.

The D.O.F. was calculated using the Gruebler's criterion.

$F = 3(N - 1) - 2P1 - P2 = 1$ where, $N = 4; P1 = 4; P2 = 0$

4. DESIGN AND ANALYSIS

4.1 Bio Inspired Link

Our project involves a bio-inspired link that will be used in the place of Rocker Bogie suspension, where it is inspired by the human body. The human body is the most advanced control system in the world the design is inspired from the joints of human limbs under controlled actions like self-balancing of our posture while riding a bicycle under uneven terrain, etc.

Fig -2: Cycling profile compared to the link

The movement of the link under uneven terrain is illustrated as below:

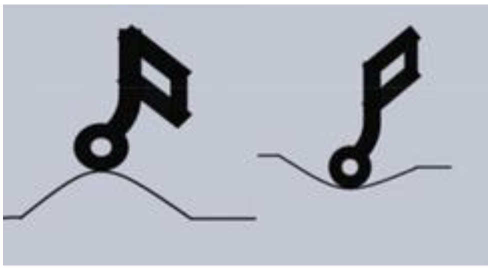

Fig -3(a) & (b): Displacement of the links

The (Fig.3 (a) & (b)) designs show the displacement of the link when it approaches a bump and a ditch respectively.

4.2 Modelling

All the links were modeled and assembled using SolidWorks. These design modifications were later incorporated before the fabrication of the robot. The final model of assembled links (Fig. 4) and robot (Fig. 5) are given below. The tabulated summary of dimensions is mentioned below.

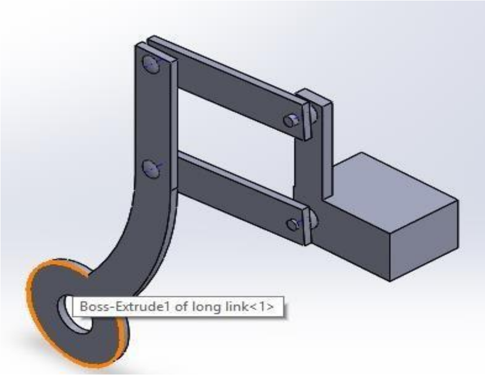

Fig -4: J-Link

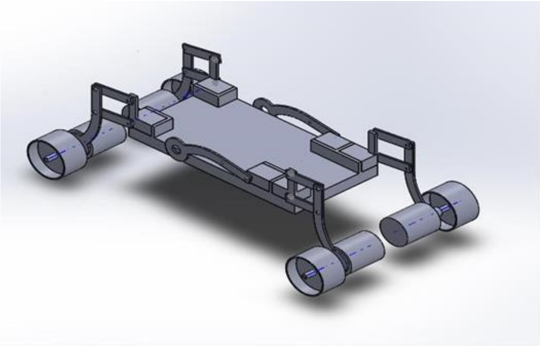

Fig -5: Assembled Robot

4.3 Kinematic Analysis

Kinematic analysis was performed to –

Ensure the tire moves in a straight line and has no angular velocities are imparted (Fig. 6(a))

To find the relation of velocities with respect to the servo angular velocity (Fig. 6(b))

The following velocity diagrams were drawn for analysis –

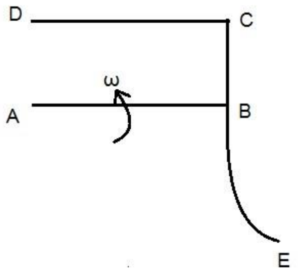

Fig -6(a): Line Diagram

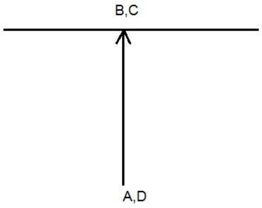

Fig -6(b): Velocity Diagram

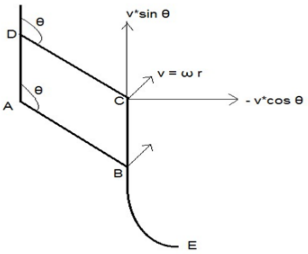

Fig -6(c): Linear Velocity Relation

From Fig. 6(b), $V_{c,b} = 0$. This implies that there is no relative motion between points B and C. Since the link is rigid, there is also no relative motion between B and E. Another diagram depicting the linear velocities was drawn to find the horizontal and vertical components of velocities (Fig. 6(c))

Therefore, linear velocity of link BC in y-direction = v x sin θ

Linear velocity of link in x-direction = -v x cos θ

4.4 Structural Analysis

Static structural analysis using ANSYS was performed on the link to see how much deflection (Fig. 7) and how much stress is developed (Fig. 8) on the application of a different amount of forces to find out the payload carrying capacity of the link. The material for simulation is ABS (Acrylonitrile Butadiene Styrene) as all our links were supposed to be 3D printed, their properties are as follows -

a) Modulus of Elasticity = 2000 N/mm^2

b) Density = 1020 Kg/m^3

c) Ultimate Tensile Stress = 30 N/mm^2

d) Poisson's Ratio = 0.394

e) Shear Modulus = 318.9 N/mm^2

Displacement Vector Solution for J link

- Force applied = 15N,
- Maximum deflection= 0.87819 mm

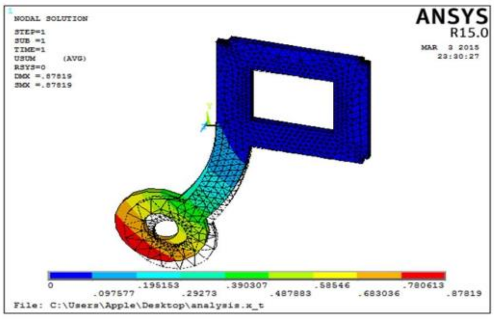

Figure -7: Displacement Vector for J-Link

Von Misses Stress Solution for J link

- Force applied = 15N,
- Maximum Stress Induced = 16.9216 N/mm^2
- Ultimate Tensile Stress = 30 N/mm^2 (Design is safe; FOS≈1.77)

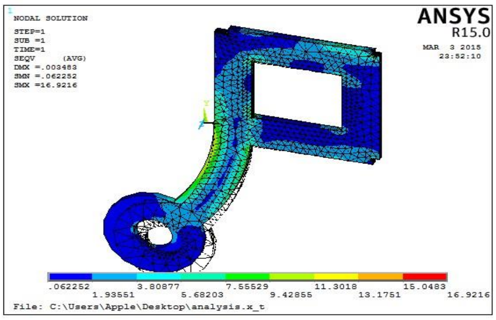

Figure -8: Von Misses Stress for J-Link

Stress analysis of the initial bent link

There was also static-analysis carried out on an alternate link design (conventional laid back bent link) to showcase the efficiency of our link selection. The static analysis proved J link is a safer design and has a lesser stresses induced, resulting in lesser chance of failure (Fig. 9).

- Maximum stress induced (corner) = 37.2346 N/mm^2
- Ultimate Tensile Stress = 30 N/mm^2

The design is therefore unsafe for the same load.

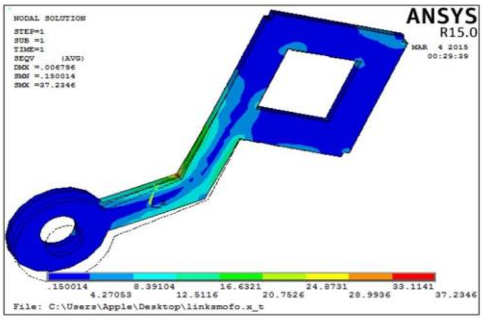

Figure -9: Stress analysis of initial bent link

The robot can, therefore theoretically lift loads to 6 kg. This weight also includes the robot's weight. On actual testing of limits after prototyping, the robot could safely lift a total of 5768 gm.

Robot weight = 1845 gm

Additional payload = 3923 gm.

At this weight, the servo motors and links had reached their limit and started to deform and twist. This result was consistent with all the Simulations performed on ANSYS.

5. RESULTS

It can be seen that how the suspension system is effective and how it maintains 0 degrees in both pitch and roll when it'll pass over a bump. A real-time graphs of angle (pitch) v/s time were plotted. A comparison of the graphs with the robotic suspension inactive and active are shown in Fig 10 (a) and (b) respectively.

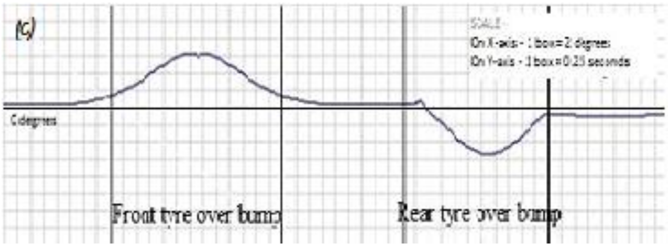

Fig -10(a): Inactive Suspension System

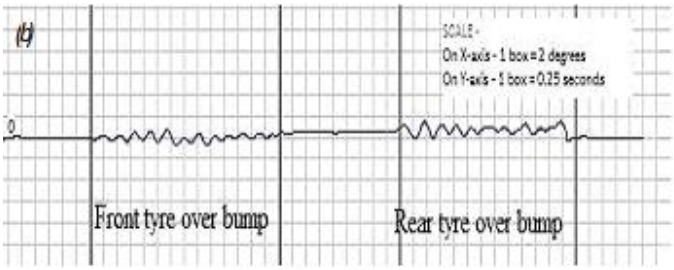

Fig -10(b): Active Suspension System

As evident from the graphs, the accuracy of our suspension system would be about 0.5 degrees.

Even though there were minor vibrations in the chassis, the robot's auto-stabilization works perfectly.

6. CONCLUSIONS

- The primary goal of achieving a robotic suspension system that maintains a nearly horizontal chassis through a variety of terrains was largely satisfied.
- The negative feedback loop in the code resulted in extremely high accuracies of about 0.1 degrees, which is way more than what was aimed for.
- Also, the code written resulted in auto–stabilization, and recovery from any angle, something which wasn't intended to be one of the objectives, to begin with. Two major problems with the design were identified.
- There was an additional supporting strip attached to the terrain to prevent the wheels from diverging, and instead follow a steady straight path along the track.
- The robotic suspension system is designed for a slow-moving robot as most space exploration robots are slow-moving. The same suspension system may not work as efficiently for a fast-moving robot. Thus it is important to note that robots with these suspension systems should ideally not be used for high-speed operations.
- The prototype that we have created did not have a motor driving circuit or a steering mechanism as they were both beyond the objective of the project.

Changes that can be implemented for Full- Scale Model

- The speed (in rpm) of each wheel is equal to 10. After thinking about the suspension system's practicality, we agreed that it would be effective for relatively higher speeds as well.
- The servo motors used will be more than suffice for our prototype due to their accurate response. However, for a scaled-up version of the prototype, stepper motors will be needed to handle comparatively heavier loads.
- Code for a larger prototype can include speed and acceleration control of the stepper motor to avoid jerks. Advanced control systems and higher-order stabilization will make the actuation vibration jerk free.
- An Arduino Uno's prowess of storing local variables is not very efficient. This means that higher processing power will be required for the controller to perform other tasks.
- The code used for interfacing the microcontroller, IMU, and the servo motors are not limited to the prototype that we have created. Changing the mapping using the equations in the code should work for a scaled-up model as well.
- Although the material used is durable and may sustain loads of up to 6 kg, it is recommended that a stronger yet lighter material, like composites, be used for a scaled-up model or greater payload capacity.
- For a scaled-up model, a ball bearing would be much ideal to join the 2 links as it provides smoother mobility and higher stability.

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