STAIR CLIMBING ROBOT: DESIGN AND DEVELOPMENT

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ABSTRACT

This paper presents the design, development and implementation of a stair climbing robot. The design works on coordinated movement between the five wheel-five motor structure. The flexibility of the skeleton is the key aspect that drives the concept behind this robot. A tailor made algorithm for this structure presides as the brain behind the functioning. It incorporates the sonar feedback with the instantaneous motion to provide rapid response allowing synchronous movement. The highly accurate deformations proved to be the biggest hurdle of the project. Experimental results reveal an excellent stair climbing performance with exceptional flexibility.

1. INTRODUCTION

The evolution of man, a worldwide accepted theory, put forward by Charles Darwin paints the picture on how humans have evolved with every single step they make. Agility with increased efficiency and effectiveness is one such evolutionary aspect of man. The fact that humans develop over time has inadvertently made a significant change in our lifestyle, most profoundly in locomotion. With the coming of the new age, we humans have devised various theories and implementations to make this particular aspect breach its boundaries. The discovery of the wheel was the turning point of human locomotion. This was the giant of locomotion in the world of legged motion. In no time man put it to use and the monstrosity of the impact it made is seen today. Everything from the nimble and agile Formula One Ferraris to the massive passenger airliners such as the Airbus runs on this amazing concept.

Thus, for our concept design we painted ourselves a raw combination of power wheel motion and structural flexibility. This was the ignition point of our robot. The more common approach for a stair climbing robot is employment of powerful actuators to achieve similar climbing success but we thought differently. We knew that venturing into a zone such as stair climbing would make perfect environment for a research project when considering the fact that most of the autonomous locomotive attention has been spanned mostly on both even and uneven terrains. From the few that stand out from the crowd we see Asimo, the stair climbing robot engineered by Honda as well as the RHex, the hexapod robot hold the crowning positions of modern day stair climbing robots. Other stair climbing robots include the Loper which employs the use of four rotating Tri-lobe wheels and the Shrimp rover which combines wheels and self-adjustable linkages to maintain suitable body posture and to increase its mobility on uneven terrains and stairs.

Now based on our concept design we would end up with a robot which is power driven by means of wheels and capable of astounding deformations. The deformations that we seek are not available through approach of basic movable joints but instead a synchronous skeleton with uniform and steady flexing was what we directly aimed for. Let me breakdown our approach into a simpler level. In order to ensure a smooth, coordinated and stable climb we would need quite a number of power driven wheels. But here too we face a compromise as higher the count of power driven wheels, higher the power consumption and thus, lower the economy. So in the end we decided on a solid five leg-five wheel design. Each leg is connect at the end to a motor driven wheel while the remaining ends meet up and dissolve into the flexible and highly deformable central skeleton. The key concept behind coordinated movement is simple. For instance, in the case of a stair climbing robot with two mechanical legs, the machine incorporates them in such a way that the ascent and descent requires the robot to maintain support on one leg, while swinging the other leg and bending the support leg to compensate for the level change. Now picture the same process for a five leg-five wheel design. The fundamentals remain the same but the swing motion is replaced by a more coordinated and aligned path following wheel.

2. METHODOLOGY

The whole concept that drives the robot is built upon the basic fundamental flexibility and deformation of the bot. This means that the central skeletal platform is the most important component and should be the starting point of our design. Perfecting the central body took a long time as eliminating and resolving all flaws required intense testing and analysis. In order to provide a light weight but high-in-strength structure we decided that the compromised metal of choice would have to be aluminum. The robot has a total of five legs connected to the central platform. The rearmost is the only body with two wheels driven by a single high powered motor. The rest of the legs all have just one wheel driven by individual motor heads. Weighing just 2.78kg, the bot spans 230mm in length, 110mm in width and 200mm in height. The distance between the hips of the rear wheels and those of the front is 190mm and the distance from the wheel hips to the bottom of the robot is 60mm.

The body of the robot is equipped with three sonars in total. These three sonars operate in a cooperative manner allowing the bot to arrive at certain logical conclusions which is highly important for proper functioning it. The first sonar is located at the bottom frontal edge of the robot somewhere close to the bottom edge of the wheels. The second sonar is also positioned along the same vertical axis as the first sonar but at the head of the robot. Both sonars face directly forward, aware of immediate obstacles both high and low. The third and last sonar is positioned close to the second sonar near the head of the bot but in this particular case the sonar is held place down. This sonar is used in the calculation of the step height. Now if we breakdown the capabilities of the sonar system into simpler terms it basically detects an obstacle and decides whether it is a wall or stair. In the instance of a stair the robot will start its ascent. It is during this process that the other features buzz in. The sonars are coded to work in such a way that the robot can calculate the height and width of the step that is being climbed. Further understanding of the sonar procedure could be done by looking into the flow chart in fig. 4. This is the backbone algorithm that runs through the robot's programming.

As flexibility is our main driving force almost the entire motion depends on it. The process of climbing a step as seen by the eye of the robot is explained in the detailing that follows. As a normal ground vehicle would follow an even path, the robot travels smoothly forward. The brain functions in the way which is explained by the flowchart but what happens in the process of climbing is totally in the hands of the mechanics of the structure. The front wheels make contact with the step and a high frictional force would develop between the tires and the surface aiding its climb. Now when the climbing starts the front wheels lift but at the same time the rear wheels are still at ground zero. It is here that the flexibility kicks in. The central body deforms and aligns itself perfectly in a manner such that the front wheels and the rear wheels could manage massive differences in terms of elevation. This allows the robot to hug the surface of the stair throughout its climb. Once the step is cleared the bot springs back into its original form. To obtain a clearer picture of this process refer fig. 1 below.

The central body should however be capable of containing the circuitry and the power source without an issue. To make this possible we included a horizontal spacious platform that hugged the deformations but still remained solid. The motors that we initially tested with had extremely high rpms and therefore we encountered certain stability related problems. As a solution to this particular issue, we decided on replacing the motors with lower specifications. The final model has five motors each running at 160rpm. This leaves us with two revolutions per second. A rotational speed this low helps us keep the motion under better control allowing the climbing process to be carried out in a more accurate and precise manner.

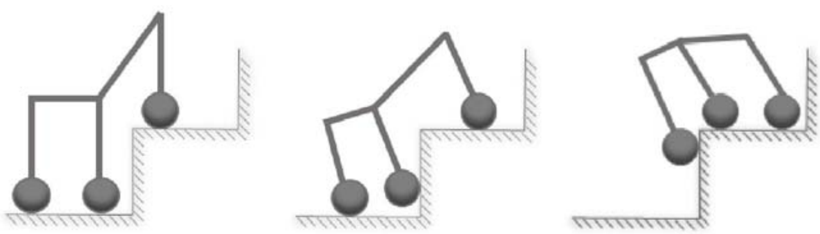


Fig. 1: The concept of the flexible structure hugging the step as it moves forward making its ascent.

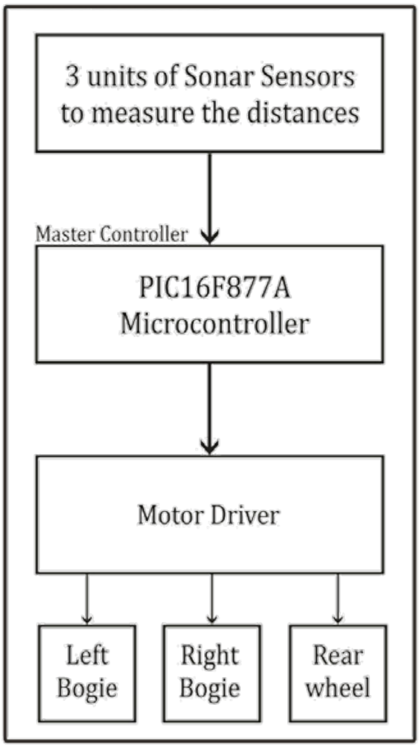


Fig. 2: Schematic of the control system

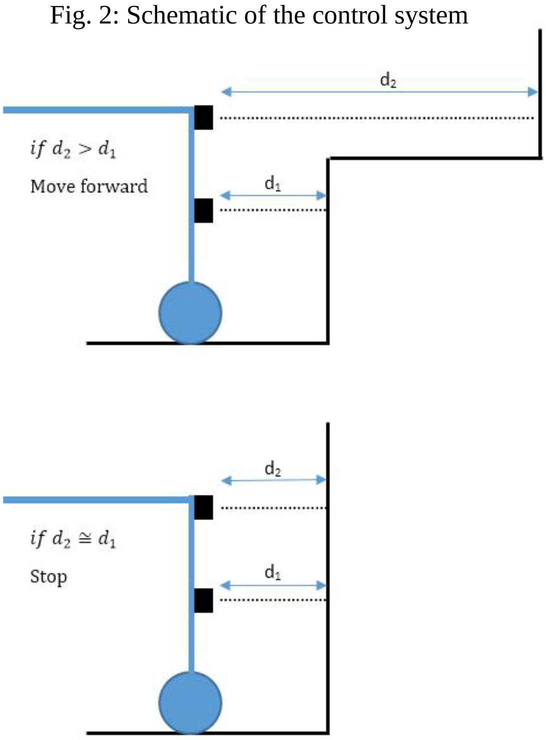
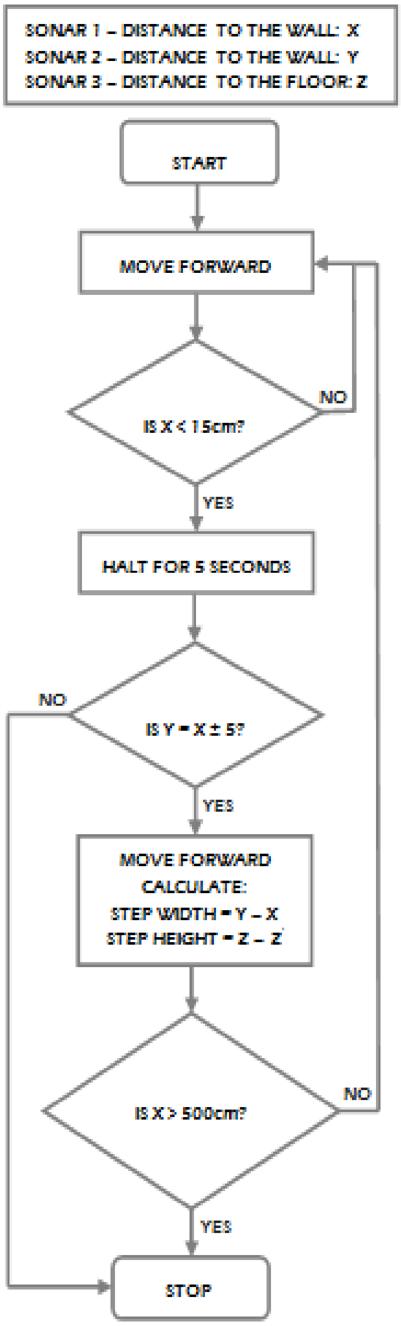


Fig. 3: Concept behind sonars



SONAR 1 AND 2 FOLLOW THE SAME VERTICAL ALIGNMENT BUT SONAR 1 IS POSITIONED NEAR BOTTOM RIM OF WHEELS WHERE AS SONAR 2 IS POSITIONED AT THE HEAD OF THE ROBOT.

Fig. 4: The backbone algorithm

3. CALCULATIONS

As illustrated on the following page Fig. 5 shows the prerequisite condition to make sure that the robot's rear wheel ascends the step. Fig. 6 illustrates situation critical. From the first figure shown above we concluded that the height of the step being climbed would not be affected by the height of the robot. But in addition to this particular result the second illustration also gives the same result in the event of a critical ascend. Fig. 7 shows how we draw the accurate condition that needs to be satisfied in order for the robot's midriff to make its ascent. Thereby we can safely state that the height of the robot should be greater than the step size with reference to the results derived. This particular collaboration of calculations was what helped up determine compromised dimensions for the robot that we have developed today. One could say that this was the ignition point.

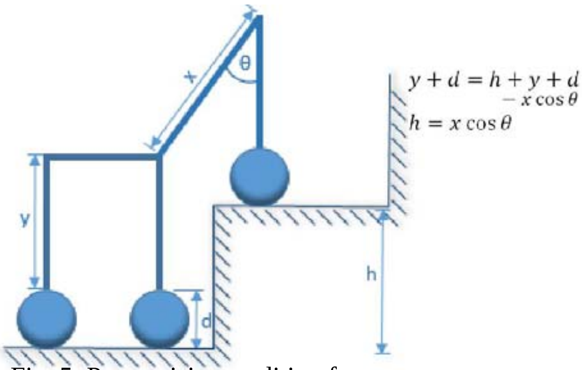


Fig. 5: Prerequisite condition for ascent

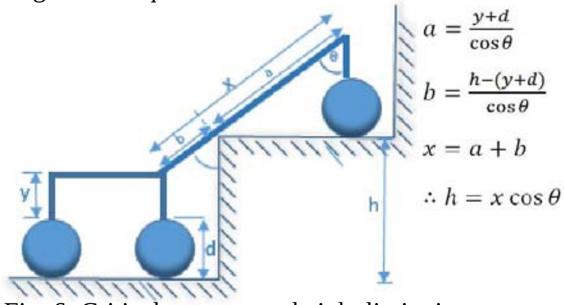


Fig. 6: Critical state – step height limitations

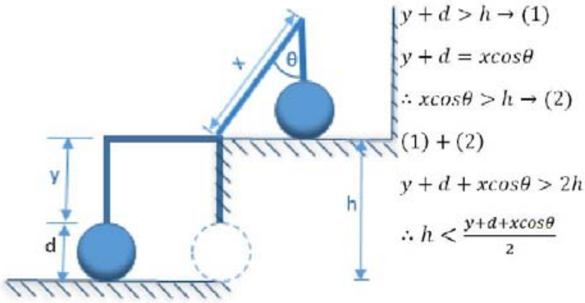


Fig. 7: Theoretical state – limits of movement

4. RESULTS

From numerous calculations and experiments we learnt that the height of the step being climbed had to be smaller than the overall height of the robot. This is as one might say, a prerequisite for ascending. The fact that we had only five wheels which were power driven showed a significant drop in power consumption when compared to other concepts. The low mass contributed to this decrease. The frame proved to be an extraordinary transformation in terms of flexibility and movement. The inclusion of sonars greatly helped in the calculations involved with step increasing the scope of our robot. It along with the programming that ran in the brain of the robot allowed perfect synchronous and coordinated movement.

5. CONCLUSION

The fact that we chose aluminum bars to manufacture and piece together our robot proved to be a huge advantage. The solid but relatively low weight metal balanced out all the negative effects. Having a solid structure also played a crucial role in the robot's continuous movement. Designing a working robot with minimal components was challenging but was worth hard work. In essence we had developed a robot that ran on the simplest of skeletons, weighing as little as possible. The tiny overall mass of the robot made all the difference as the total consumption reduced drastically showing high efficiency of the product. Running the device on the sole concept of flexibility and large deformations proved to be the greatest of all advantages. Maximizing the overall movable joints all over the structure not only smoothened the process but allowed heavy deformations with ease. The result – A highly agile and fast step climbing robot. The compromised but comparatively long length of the robot helps provide an almost even distribution of weight. This particularly long but compromised dimensioning is perfection allowing the robot to hug step and climb it in the most delicate of manners. When compared to most step climbing robot (especially the six wheeled robot and the actuator driven bots) the robot that we managed to end up with showed numerous advantages over them. Our robot was easily the faster and the more flexible.

6. REFERENCES

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