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Design and Fabrication of Motorised Stair Case Climbing Trolley

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Abstract

Despite rapid changes in the way the things are being manufactured, we are still used to the age of techniques of manufacturing. The reasons are multifold ranging from inertia, rejection of the new technologies, lack of engineering aptitude, lack of skill & technical know-how and most importantly fear of losing employment opportunities. This project aims at developing a mechanism for easy transportation of heavy loads over stairs. The need for such a system arises from day-to-day requirements in our society. Devices such as hand trolleys are used to relieve the stress of lifting while on flat ground. However, these devices usually fail when it comes to carrying the load over short fleet of stairs. In the light of this, the project attempts to design a stair climbing hand cart which can carry heavy objects up the stairs with less effort compared to carrying them manually. In present project, the trolley is equipped with Tri-Star wheels which enable us to carry load up and down the stairs and also eases the movement of trolley in irregular surfaces like holes and bumps.

Keywords: Tri-Star wheel, Wheel frame, Hybrid stepped motor, Step angle, Step length.

INTRODUCTION

Stair Climbing is a key functionality desired for robots deployed in Urban Search and Rescue (USAR) scenarios. A novel compliant modular robot was proposed earlier to climb steep and big obstacles. This work extends the functionality of this robot to ascend and descend stairs of dimensions that are also typical of an urban setting. Stair Climbing is realized by equipping the robot's link joints with optimally designed passive spring pairs that resist clockwise and counter clockwise moments generated by the ground during the climbing motion.] Sonukumar Krishnaprasad Singh et.al[2017] are presented a paper on Design & Fabrication of semi-automatic stair climbing trolley. P.JayPraveenrajet.al.[2016] are given the modifications in the trolley design of their paper on Design and Fabrication of stair climbing trolley. M.M.Mogaddam and M.M.Dalvand [2005] have submitted a paper on Stair climbing mechanism for Mobile Robots. A.S.Shriwaskar and S.K.Choudary[2013] are presented an article on Synthesis,Modeling ,Analysis and Simulation of stair climbing mechanism. M.-S. Wang and Y.-M. Tu, [2008] are presented a paper on the Design and implementation of a stair-climbing robot. Q. Zhang, S. S. Ge, and P. Y. Tao [2011] are considered Autonomous stair climbing for mobile tracked robot in their project to develop the robotics . Murray J. Lawn [2003] has investigated the Modeling of a stair-climbing wheelchair mechanism with high single-step capability. Luc Jaulin [2007] are presented a paper on the Control of a wheeled stair-climbing robot using linear programming. Sri Harsha Turlapati [2015] are submitted an article on Stair Climbing Using a Compliant Modular Robot. Md. Farhad Ismail [2012] are proposed the Fabrication of a Stair Climbing Vehicle for Industrial and Rescue application Using Appropriate Technology in their article. Jinguo Liu [2005] are presented a paper in proceedings on Analysis of Stairs-Climbing Ability for a Tracked Reconfigurable Modular Robot.

THEORY & COMPONENTS

In day-to-day life we need to carry some goods and objects through stairs especially in offices, schools, colleges, hotels, industries, apartments etc. where the lifts may not be available, may be crowded with people or under repair .It is difficult to carry various objects through stairs manually for higher floors. A stair climber is a type of trolley fitted with rotating wheels or tracks so that it can be pushed or pulled up or down steps or a stairway. Stair climbers can be manual or battery-powered, and are commonly found in wheel, track, and push arm or walker variants.

Tri-Star Wheel

The Tri-Star wheel was designed in 1967 by Robert and John Forsyth of the Lockheed Aircraft Corporation. They were first developed as a module of the Lockheed Terrastar, a commercially unsuccessful amphibious military vehicle. A Tri-Star wheel functions as an ordinary wheel on flat ground, but has the ability to climb automatically when an impediment to rolling is encountered. This wheel design consists of three tires, each mounted to a separate shaft. These shafts are located at the vertices of an equilateral triangle. The three shafts are geared to a fourth, central shaft (to which a motor may be attached). When geared in this quasi-planetary fashion, these triangular sets of wheels can negotiate many types of terrain, including sand and mud; they can also allow a vehicle to climb over small obstructions such as rocks, holes, and stairs. The wheel assembly may be gear-driven, with two wheels in rolling contact with the ground. The third wheel idles at the top until the lower front wheel hits an obstruction. The obstruction prevents the lower front wheel from moving forward but does not affect the motion of the driving axle. This causes the top wheel to roll forward into position as the new front wheel. This wheel usually lands on top of the obstruction and allows the rest of the assembly to vault over the obstruction. Tri-Star wheel in motion is shown in figure2.1.

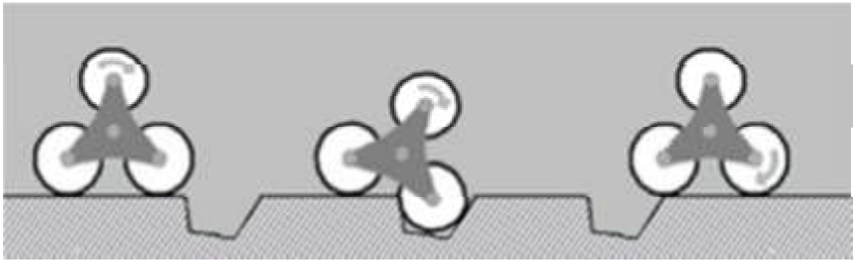

Figure 2.1: Tri-Star wheel in motion

Stepper Motor

Stepper motor is a special type of electric motor that moves in precisely defined increments of rotor position (Steps). The size of the increment is measured in degrees and can vary depending on the application. Due to precise control, stepper motors are commonly used in medical, satellites, robotic and control applications. There are several features common to all stepper motors that make them ideally suited for these types of applications. They are as under High accuracy: Operate under open loop Reliability: Stepper motors are brushless. Load independent: Stepper motors rotate at a set speed under different load provided the rated torque is maintained. Holding torque: For each and every step, the motor holds its position without brakes. Stepper motor requires sequencers and driver to operate. Sequencer generates sequence for switching which determines the direction of rotation and mode of operation. Driver is required to change the flux direction in the phase windings.

Hybrid Steped Motor

The term HYBRID is derived from the fact that motor is operated with the combined principles of the permanent magnet and variable reluctance motors in order to achieve small step length and high torque in spite of motor size. Standard HSM have 50 rotor teeth and rotate at 1.8 degree per step. The windings are placed on the stator poles and a PM is mounted on the rotor. The important feature of the HSM is its rotor structure. A cylindrical or disk-shaped magnet lies in the rotor core. Stator and rotor end-caps are toothed. The coil in pole 1 and pole 3 is connected in series consisting of phase A and poles 2 and 4 are for phase B. If stator phase A is excited pole 1 acquires north polarity while pole 2 acquires south polarity. Pole 1 attracts the rotors south pole while pole 3 aligns with the rotors north pole.When the excitation is shifted from phase A to phase B, in which case the stator pole 2 becomes north pole and stator pole 4 becomes south pole, it would cause the rotor to turn 900 in the clockwise direction. Again phase A is excited with pole 1 as south pole and pole 3 as north pole causing the rotor to move 900 in the clockwise direction.

If excitation is removed from phase A and phase B is excited, then pole 2 produces south pole and pole 4 produces north pole resulting in rotor movement of 900 in the clockwise direction. A complete cycle of excitation for the HSM consists of four states and produces four steps of rotor movement. The excitation state is the same before and after these four steps and hence the alignment of stator/rotor teeth occurs under the same stator poles as explained by Kenjo (1984). The step length for a HSM and angle through which the rotor moves for each step pulse is known as step angle and is calculated by

Step length $=90^0/Nr$

Step angle is calculated using the formula

$$\theta = \frac{360}{m * N_r} \quad \text{or} \quad \theta = \frac{360(N_s - N_r)}{N_s * N_r}$$

Where,

θ - Step angle in degrees

N_s - Number of stator teeth

N_r - Number of rotor teeth

m – Number of phases

Mechanical angle represents the step angle of the step. In the full step mode of a 1.8° motor, the mechanical angle is 1.8°. In the 10 micro step mode of a 1.8° motor, the mechanical angle is 0.18º. An electrical angle is defined as 360° divided by the number of mechanical phases and the number of micro step. In the full step mode of a 1.8° motor, the electrical angle is 90°. In the 10 micro step excitation of a 1.8° motor, the electrical angle is 9º.

Battery

The batteries in which a reversible reaction is responsible for the generation of electricity such that they can be reverted to the original reactant state fall under the category of secondary batteries. Recharging is effected by passing electric current through the battery. The oldest form of rechargeable battery is the Lead-Acid battery. Lead Acid battery market is dominating primarily because of the unavailability of any able competitive solution in the market and that they offer lowest cost per watt-hour despite of their low specific energy. The desire to make these batteries maintenance free, the flooded battery type evolved into two variants: Sealed Lead Acid or Gel cells and valve regulated lead acid (VRLA) Batteries. .

Epicyclic Gear

A planetary gear train is a little more complex than other types of gear trains. In a planetary train at least one of the gears must revolve around another gear in the gear train. A planetary gear train is very much like our own solar system, and that's how it gets its name. In the solar system the planets revolve around the sun. Gravity holds them all together. In a planetary gear train the sun gear is at the centre. A planet gear revolves around the sun gear. The system is held together by the planet carrier. The planetary gear set is the device that produces different gear ratios through the same set of gears

Wheel Frame

A specially designed wheel frame is required to hold the motors together on each side of the shaft. In the existing design, the power transmission to the single or double wheel is useless to climb the stairs due to height factor of stairs. The design of the straight wheel frame became more complicated and was needed to be modified with its curved- spherical shape to give proper drive, which creates more frictional force. For these reason, three wheel set on each side of vehicle attached with frame was introduced to provide smooth power transmission to climb stairs without much difficulty. Frame arrangement is suitable to transmit exact velocity ratio also. It provided higher efficiency and compact layout with reliable service. The wheel frame is shown in fig.2.2.

Figure 2.2: wheel frame

TB6600 Stepper Motor Driver SKU: DRI0043

TB6600 Arduino Stepper Motor Driver is an easy-to-use professional stepper motor driver, which could control a two-phase stepping motor. It is compatible with Arduino and other microcontrollers that can output a 5V digital pulse signal. TB6600 Arduino stepper motor driver has a wide range power input, 9~42VDC power supply. And it is able to output 4A peak current, which is enough for the most of stepper motors.

The stepper driver supports speed and direction control. You can set its micro step and output current with 6 DIP switch. There are 7 kinds of micro steps (1, 2 / A, 2 / B, 4, 8, 16, 32) and 8 kinds of current control (0.5A, 1A, 1.5A, 2A, 2.5A, 2.8A, 3.0A, 3.5A) in all. And all signal terminals adopt high-speed optocoupler isolation, enhancing its anti-high-frequency interference ability.As a professional device, it is able to drive 57, 42-type two-phase, four-phase, hybrid stepper motor.

Specification		**Requirements**
Input Current:	0~5A	Hardware
Output Current:	0.5~4.0A	1 x DFRduino UNO R3
Control Signal	3.3~24V	1 x TB6600 Stepper Motor Driver
Power (MAX):	160W	1 x Stepper motor
Micro Step:	1, 2/A, 2/B, 4, 8, 16, 32	Software
Temperature:	-10～45℃	Arduino IDE
Humidity:	No Condensation	
Weight:	0.2 kg	
Dimension:	96 * 71 * 37 mm	

Connection Diagram

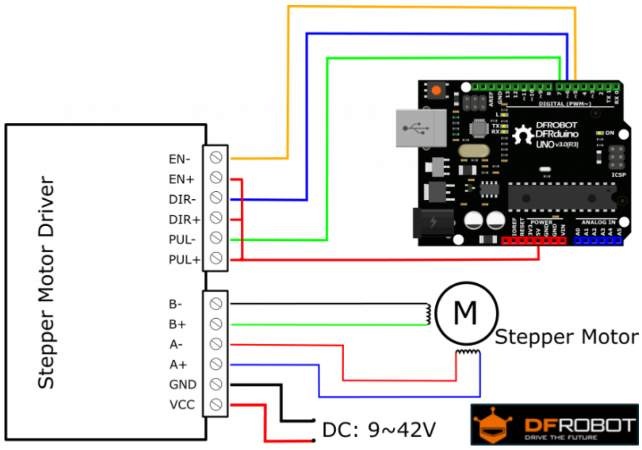

Figure 2.3: Circuit Diagram

1. In this tutorial, we'll use a bipolar stepper motor, 1.8 step angle, 1.7A
2. Set current: 1.7A
3. Set Micro Step: 32
4. Connect a 9~42V DC power supply

Roller Chain

Roller chain or bush roller chain is the type of chain drive most commonly used for transmission of mechanical power on many kinds of domestic, industrial and agricultural machinery, including conveyors, wire-drawing and tube-drawing machines, printing presses, cars, motor cycles and bicycles. It consists of a series of short cylindrical rollers held together by side links. It is driven by a toothed wheel called a sprocket. It is a simple, reliable, and efficient means of power transmission.

Sprocket

A sprocket or sprocket-wheel is a profiled wheel with teeth, or cogs,[3][4] that mesh with a chain, track or other perforated or indented material.[5][6] The name 'sprocket' applies generally to any wheel upon which radial projections engage a chain passing over it. It is distinguished from a gear in that sprockets are never meshed together directly, and differs from a pulley in that sprockets have teeth and pulleys are smooth. Sprockets are of various designs, a maximum of efficiency being claimed for each by its originator. Sprockets typically do not have a flange. Some sprockets used with belts have flanges to keep the timing belt cantered.

CALCULATIONS

Tri-Star Wheel Design

Deriving the Tri-Star wheel parameters depends on the position of Tri-Star wheel on stairs. It depends on two parameters, the distance between the edge of wheel on lower stair and the face of the next stair(L1), and the distance between the edge of wheel on topper stair and the face of next stair (L2), as shown in Figure 3.1.

By comparing these parameters, three states may occur as follow:

1. L1 < L2 2. L1 >L2 3. L1 = L2

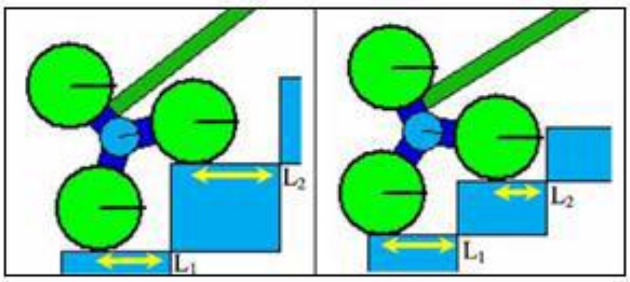

Figure 3.1 (a)

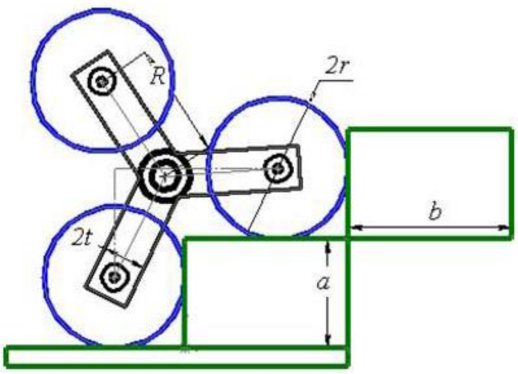

Figure 3.1(b)

Based on these states, the third states (L1 = L2) will be used as the reference of project to design the Tri-Star wheel. In this case, the L1 and L2 don't change and remain constant while climbing stairs. Therefore the case (1) and case (2) are not suitable since the robot will encounter the problems while climbing stairs, but the case (3) is suitable for climbing robot smoothly. It should be noted that the value of L1 and L2 for derivation of the parameters maybe any values but equal. L1 and L2 are assumed equal to the radius of angular wheel (L1=L2=r). In the design of Tri-Star wheel, five parameters are important which are the heights of the stairs (a), width of stairs (b), radius of regular wheel (r), radius of Tri-Star wheel, the distance between the centre of Tri-Star wheel and the centre of its wheel (R) and the thickness of holders that fix the wheel on its place on Tri-Star wheel ($2t$), as shown in Figure 3.1b.

According to the project requirements, the value of (a) and (b) are determined as

$$a= 15 \text{ cm}, b = 29 \text{ cm}, r = 3.5\text{cm}$$

$$R=\sqrt{\frac{a^2+b^2}{3}}=\sqrt{\frac{15^2+29^2}{3}}= 18.85\text{cm}$$

The minimum value radius of regular wheel (r_{min}) to prevent collision of the holders the stair is derived as

$$r_{min}=\frac{6Rt+a(3b+\sqrt{3a})}{(3-\sqrt{3})a+(3+\sqrt{3})b} =\frac{6*18.484+15(3*29+\sqrt{3*15})}{(3-\sqrt{3})15+(3+\sqrt{3})29} = 8.43 \text{ cm}$$

The maximum value radius of the regular wheels (r_{max}) to prevent the collision of the wheels together is

$$r_{max} = \sqrt{\frac{a^2+b^2}{2}}= \sqrt{\frac{15^2+29^2}{2}}= 23.08\text{cm}$$

The maximum value of the thickness of holders to avoid collision between the holders and stairs is derived by

$$t_{1max} = \frac{ar(3-\sqrt{3})+br(3+\sqrt{3})+a(\sqrt{3a}-\sqrt{3b})}{6R}= \frac{15*4(3-\sqrt{3})+29*4(3+\sqrt{3})+15(\sqrt{3*15}-\sqrt{3*29})}{6*18.85}= 5.17 \text{ cm}$$

For, knowing the amount of r and R, we can derive the maximum height of stairs that the robot can pass through it

$$a_{1max} = \sqrt{a^2 + b^2 - r^2}= \sqrt{15^2 + 29^2 - 4^2}= 32.4037\text{cm}$$

For traversing the stairs with the maximum height, the half thickness of the holder must be in the following range.

$$t_{2max} = \frac{r(r+\sqrt{3(a^2+b^2-r^2)})}{2\sqrt{a^2+b^2}}= \frac{4(4+\sqrt{3(15^2+29^2-4^2)})}{2\sqrt{15+29^2}}= 3.68\text{cm}$$

Motor Requirement: This mechanism is powered by stepper motor. Maximum velocity is 5cm/s. Total mass of the wagon (30kg).

Power = force * velocity = m*g* = 30*9.8*05= 147 Watts

So, the mechanism consists of a stepper motor would be required to move the vehicle. A battery of 150W power to be required.

WHEEL HOLDERS

This system consists of four wheel holders of MS plate with 2mm thickness. A bush is welded together to hold the shaft by a nut. As shown in figure.3.2.

Figure 3.2: wheel holder

RESULTS & ANALYSIS

The vehicle was moving well over the stair. It can move on flat surface uniformly at 20 rpm without any fluctuation and there was no variation of speed over steps. It was observed that there was very low noise and vibration over flat surface or stair. It was observed that the vehicle was disturbed when it faced the stair of different step sizes. This was because of the shape and size of the wheel frame. Therefore for a range of stairs size can be considered for this vehicle. Although, different sizes step are not usually available in building design. It showed good performance when the step size was uniform. Here in this project separate frame can be used to move over the stair of different size and shape, which made its use over wide range of size of stairs. From the test run of the vehicle it was seen that the maximum height the vehicle could climb the stair whose inclined angle was 44° maximum. If the inclination is more than 44° it would fail to climb the stair. In building construction, very few stairs are generally available having inclination more than that i.e.44°. The smooth ramp angle (θs) was not listed for the vehicle. But it can be easily predicted that stair inclined angle (θ) is less than that of ramp (θ_s). This is shown infig.4.1.

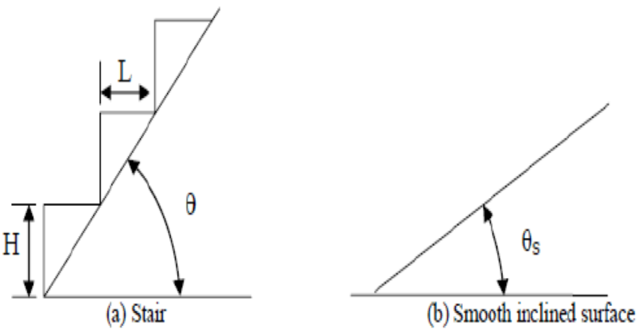

Figure 4.1: Maximum climbing angle, (θ, θ_s)

The velocity of the vehicle during climbing the stair was higher than that on the flat surface as the wheel frame (higher radius) was used to climb stair. The velocity of the vehicle on the stair was 55 in/hr. However; the speed of the vehicle running on a ramp was not measured. This speed should not be higher or equal to the speed on the horizontal surface. From the above discussion, it could be summarized that considering some of the limitations, the vehicle was an effective alternative to transport loads using stairs. Some limitations could not be avoided because of the lacking in technological availability. This pioneer project, with a little further improvement, was hoped to be succeed to meet up the demand of carrying loads over the stair.

CONCLUSIONS

The design of the trolley is compact and hence is able to move about in almost all the stairs that we find at institutions, offices, industries and also at some homes. The design is made very safe and there is no chance of failure of the frame and wheels under normal condition.

According to the tests conducted, the stair climbing trolley has a capacity of carrying a load of 100kgs on flat surface. It has the ability to ascend a flight of stairs of 45-degree elevation carrying a weight of 40kgs.

The main benefit of the project is stair climbing mechanism for load carrier with decreasing effort. Doing better work with lesser effort has been the main objectives of human beings in any field. This project as platform we present motorized stair case climbing trolley with reducing effort. The future enhancement of our project is we have to rectify the problems that we have encountered during descending of the trolley in stairs. We had a smooth travel while ascending but while coming down from the steps, we found some vibration problem and to overcome this we have planned to install springs and braking system, so that trolley will be in a good control while descending also.

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