Piston mechanism based rope climbing robot

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Abstract

Throughout the history of robot development, most of the subjects are based on wheeled mobile robots and are moving on the floor. In this paper, a different kind of robot design, rope climbing robot, will be discussed. It is a robot that climbs along a rope and therefore can move across the space through the rope. This robot needs only a DC motor and two servo motors for the climbing operation. The advantages of the proposed robot are low energy consumption, low cost, easy to control and build. This research is focused on the mechanical design and implementation of the robot. During the development stage, this proposed robot design was tested with 2 tasks and had been used in a rope climbing competition for a robotic competition in Malaysia. The result of the competition was very encouraging and proved that the robot design is applicable. This rope climbing robot can be applied to transport goods in a factory or transport casualty in rescue operation.

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1. Introductions

Mobile robot is a type of automatic machine which is capable of movement in a given environment. Through the mobile robots, many various tasks can be carried out to serve human, such as inspection, security and etc. Mobile robots can be built in various forms and the most popular structures nowadays are wheeled mobile robots (WMRs) and humanoid robots.

WMRs are the simplest mobile robot solution as they are simpler and easier to build and control. Thus, in the past few decades, a vast majority of the researches and projects of mobile robots were focused on the WMRs. Nevertheless, there were also researches based on mobile robots with legs and treads.

In 1983, Murthy and Raibert [1] had presented a one legged robot named 3D Hopper. Even though the 3D Hopper had only one leg, it was able to stabilize itself and move around. Zeglin [2] had developed a two legged robot named Uniroo which was kinematically similar to a kangaroo. One of the most famous two legged robot nowadays is the Honda Asimo. There are also robots with more than two legs, such as Tekken II [3], Patrush II [4], Sony’s Aibo [5] and robots that are inspired by biological insects [6].
All of the mobile robots discussed above are moving on the plain surface, automated using markers or strips laid on the floor. Rope climbing robot is another type of mobile robot. However, the medium that rope climbing robot used to move is not the floor, it is along a rope which the robot clings on to.

Different approaches had been applied on rope climbing robot. Kaya et al. [7] had introduced a wheeled robot that could be run on web by pinching the strings. This type of robot was proposed to be applied in assembling large structures in constructing Furoshiki satellite. Another type of rope climbing robot is a brachiating robot presented by Fu [8]. On the other hand, a four legged rope climbing robot had been presented by Hewaathirana et al. [9]. The robot imitated crawling motion with four legs and four grippers for steady and smooth operation. For this type of robot, the control was much more complex as each leg and gripper was powered by different motors and controlled separately by a single controller board.

The rope climbing robot presented in this paper is designed to climb rope with only one DC motor as the main actuator and two servo motors to control the forward and backward direction. Since the proposed rope climbing robot has only one DC motor and two servo motors for climbing, this robot is much easier to control compared to previous robots mentioned. Furthermore, the robot's structure is also simple thus reducing the development complexity and the total cost required to build it. This rope climbing robot can be applied in a few areas like pick-and-load operation in a factory and rescue operation where the robot can be used to transport casualties.

2. Methodology

In this paper, the methodology is discussed in two parts, mechanical design and embedded system.

2.1. Mechanical design

In this subtopic, the discussion is mainly about the mechanical part of the robot. Firstly, the conceptual design of the robot is discussed. Then, the concept of the piston mechanism is presented next. Lastly, the requirements for the actuators are also presented.

2.1.1. Robot structure

Fig. 1a shows the conceptual design of the robot, which is based on a box-shaped compartment. Fig. 1b shows the main parts of the robot that performed piston mechanism. Unlike most of other robots' structures for which the bases were made from metals' frames, this rope climbing robot’s base frame is a box-shaped compartment made from perspex. Other components and links are attached around the compartment to stabilize and lower its center of gravity to reduce the risk of flipping while in motion. Besides functioning as the base frame, the compartment is also for storage purpose and can be modified to fit with other applications such as gripper for pick-and-load operation. There are 2 clappers that made from servo motors to make sure the robot climbs in the desired directions such as forward, backward, up, down, diagonal and vertical direction. Other than the 2 servo motors used for controlling the climbing direction, an additional 1 unit of servo motor is used to control the opening and closing of the compartment.
2.1.2. Piston mechanism

As shown in Fig. 1b, the piston mechanism consists of crank, connecting rod and end bar. A DC motor is connected with the crank to rotate it. When the crank is rotated, angular motion of the crank is converted into linear motion of the end bar and input torque from the DC motor is transformed into linear force on the robot. In order for the linear motion to succeed, the end bar is attached to a slider, as shown in Fig. 1b, so that the slider will guide the end to move in linear direction. Then, with the help from the 2 clamps, the linear motion will be used to climb the rope.

2.1.3. Motors

To ensure the success rate of the robot’s climbing operation will require 2 types of motors, DC motor and servo motor. DC motor plays an important role in determining the successful of the climbing operation as the piston mechanism is powered by the DC motor. The torque generated by the DC motor is not used solely in climbing operation, but also in overcoming the friction force and the resistance force caused by the clamps with the rope, therefore, it must have high torque. After a few trial and errors with some DC motors that are available in the market, the selected DC motor was detached from a hand-drill as it can provide sufficient torque and power to overcome the resistance forces while having high speed rotation.

In this presented robot, the clamps were made to be rotary and as a stoppage to prevent the robot from slippage and going into wrong direction. In order to achieve these objectives, the requirements of the motor for the clamps are that the rotation degree is able to be controlled precisely while providing sufficient force. Therefore, RC servo motors with metal gears are selected as the motors for the clamps. Metal gear servo motors have the advantages of being suitable for heavy duty application, can be designed for closed loop feedback application and the motors’ position can be controlled easily.

Table 1 shows the brief requirements for both motor types and the specifications of both motor types.

| Motor Types             | Requirements for the motor | Specifications of the motor                                      |
|------------------------|----------------------------|-----------------------------------------------------------------|
| Hand-drill DC motor    | • High power               | • Speed: 700 rpm                                                 |
|                        | • High speed               | • Rated voltage: 12V                                             |
| RC servo motor         | • Durable                  | • Full Metal Gears                                              |
| (metal gear)           | • Provide high torque      | • Suitable for heavy duty application                           |
|                        | • Rotate with 90 degree    | • Torque (Kg-cm): 9.0/4.8V, 11.0/6.0V, 13.0/7.2V (maximum 7.2V) |
|                        | • Easy to control          | • Rotation angle: 180 degree                                    |
|                        |                            | • Designed for "closed feedback".                               |
|                        |                            | • Able to control the position of the motor                     |

2.2. Embedded system

In order for the proposed robot to function, the mechanical parts only were insufficient. It also needed an embedded system to activate and to control the robot. The first component of the embedded system that will be presented is the system architecture. Under system architecture section, the processing unit and the electronic components in the robot will be discussed. Followed by the software that was developed along with the robot development as a mean to control the robot and for the robot to perform some basic functions.

2.2.1. System architecture

The system architecture is shown in Fig. 2. The main processing unit used in this rope climbing robot is a PIC16F877A microcontroller. This microcontroller is chosen for its small size and low cost. Although the capacity of PIC’s memory is only 14KB [10], it is more than enough as the developed robot requires only simple control process and minimal programming code. All the actuators and sensors are controlled by this single microcontroller.
The power supply of the proposed system is 12V DC voltage which is supplied by a Lithium-Polymer rechargeable battery. The voltage of 12V is supplied directly to the hand-drill DC motor and the regulated 5V voltage supply is used to power up the control board. The microcontroller is used to control LEDs, 3 servo motors and the hand-drill DC motor while receiving signal from a limit switch. Generally, LEDs were used as indicators to indicate the status of the robot. The microcontroller generates pulse-width modulation (PWM) signals to control the servo motors’ rotation angle. Relay is used to switch on the hand-drill DC motor and to separate the control circuit from the high load hand-drill DC motor as a protection from physically damage to the microcontroller.

![System architecture](image)

**Fig. 2: System architecture**

### 2.2.2. Software description

A source code was developed in order to test the functionality of the rope climbing robot. The source code was developed in Micro Basic Studio using PicBasic programming language. The developed source code can be separated into two tasks. The first task is the climbing task. The rope climbing robot is required to climb up an inclined 34 degree rope until it reaches a plate that is located 4.5m away, at the top of the rope as illustrated in Fig. 3. A limit switch is located at the end of robot and as the limit switch makes contact with the plate, it shall signal the robot to proceed to second task. The second task is the dropping package task. Once the robot reaches the top end of the rope, the robot will need to climb down until the mid-point and drop down a package.

![Illustration of the position of the rope and plate](image)

**Fig. 3: Illustration of the position of the rope and plate**

Fig. 4 displays the flowchart of overall program. When the robot is started, the clamps rotate to predefined angle in order to lock the robot on the rope and to prevent slippage. Then, the robot will start climbing up the rope with the DC motor turned on and the piston mechanism in function. The mechanism is continuously in action until the microcontroller receives a signal from the limit switch that indicates the robot had reached the target, the end of the rope. The DC motor will then be stopped by the microcontroller while the clamps rotate to the next predefined angle. When the clamps reached the angle, the DC motor is started once again and the robot entered the second task. Due to the action from the clamps, the robot shall descend although the DC motor is rotated in the same direction as before. When the robot reaches the mid-point of the rope, the DC motor will be stopped immediately and the robot will drop down the package.
3. Result and discussion

This research is mainly focused on the mechanical design and implementation of the robot. Before the real robot was developed, some simulations were made based on the robot’s structure in order to verify the robot’s design. In this project, Solidwork software application and the Solidwork Motion add-in were used for the purpose of design verification. After the robot was drawn in the Solidwork, some tests were being carried out in the Solidwork’s environment. By including a random magnitude of forces on the assembly design as the friction force and setting the crank to be rotated in 100 rotations per minute (rpm) (a randomly picked value), the results are shown at Fig 5. Fig. 5(a) showed the angular velocity of the crank of the piston mechanism and Fig. 5(b) displayed the linear displacement of the end bar of Fig. 1b.

Overall, Fig. 5 shows that the robot can be moved in the desired direction as long as the clammers functions well. This could be illustrated from the linear displacement diagram. The positive slope of the linear displacement indicated that the robot had climbed forward for some distance. When the linear displacement was in negative slope, the robot is supposed to move backward, however, with the help from the clammers, this movement was transformed, only the end bar was moving but the robot was static at the point.
The developed robot is shown in Fig. 6(a) while Fig. 6(b) shows the robot in action. The robot is tested to climb a 34 degree inclined rope with the length of the rope was 4.5m. The time taken for the robot to climb up the rope until the top was 15 seconds and the total time taken for it to accomplish the 2 tasks were 20 seconds. The main advantage of this proposed robot is it does not require complicated control algorithm. In this robot, basically, the actuators that needed control are the two clammers which are to rotate them to the predefined angles before the robot starts climbing. The DC motor’s control was simple, which was to power up and to stop the DC motor, did not need to control the direction of the motor’s rotation. Other than that, due to only few motors (1 DC motor and 3 servo motors) were used, this robot’s power consumption and cost are also comparatively low.

However, there is a drawback in this presented robot which can be further improved. When the robot is in action, it will cause vibration along the rope occasionally. This is due to heavy load and the uncontrolled power from the DC motor, which can be observed from Fig. 7, graph of the DC motor’s power consumption. From the waveform of Fig. 7, we observed that there was some noise in the DC motor and it was not uniform. Nevertheless, in general, this robot design has proved to be successful as the robot can climb up and down along the rope and release the package at designated location. In future, the robot’s performance can be improved by integrating some feedback control such as PID controller into the robot in order to control and stabilize the motor’s power.
Fig. 7: Power consumption of the DC motor

4. Conclusion

This project introduces a new and effective approach for rope climbing robot. In this robot, only 1 DC motor and 2 servo motors are needed for the major task, which is the climbing operation. This system, in general, is easy to build and to control. The system had been used for a rope climbing competition for robotic competition and the result in the competition was encouraging. This presented robot design used a total of 20 seconds to accomplish both task 1 and task 2. In the future, some studies on possible improvement such as adding in PID controller to the control system, could be done in order to preserve the stability of the robot mechanism apart from increasing the linear movement with high speed performance in the rope climbing operation.

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