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Mechanism Design and Autonomous Movement and Jump Control for a Jumping Robot

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Abstract: This work introduces an autonomous jumping robot, capable of moving over the ground, and identifying obstacles as well as jumping over stairs. The robot could be employed to patrol in a building subject to stairs. The robot requires fast autonomous motion and makes use of novel jumping mechanisms to be fit into small-packed volume, reducing the weight enough to be held on human's hand. Several sensors are located on the robot including: a camera for monitoring and tracking a target, PSD (Position Sensitive Device) for distance measurements and ultrasonic sensors for alignment. Jumping is achieved using a four-bar link mechanism that pushes against the ground with the help of the compressed spring. The jumping height can be controlled by changing the tilt angle of the robot body, which allows the robot to adapt the obstacle size.

Keywords: Jumping robot, autonomous movement, link mechanism, spring compression

1. INTRODUCTION

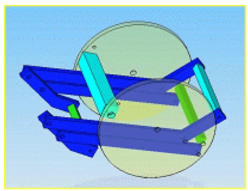
As robot technologies advance, robots need to behavior or think as like as human does. Robot intelligence is being developed but it still takes long time to mimic human as wished. As for a mechanism, even though not complete, it is commonly understood that a robot mechanism must be designed exceptionally to perform a specific function. For example the exceptionally long wheel or caterpillar tracks are used to ascend stairs. However, where the robot meets an obstacle these mechanisms may not be appropriate and therefore the size of the robot is particularly of importance without designing it with its full size directly to overcome. It is suitable therefore to look at the design of a robot in case of climbing a stair, resulting in a minimum sized robot.

In this work a jumping robot is introduced, which is a small size but is compactly packed to work distinguished tasks [1-2]. It is a floor navigating robot with wheel mechanism, designed with the role of patrolling and monitoring an environment with fast movement, whilst delivering information about the environment through a camera. In consideration of maneuvering over obstacles, several diverse methods will be investigated. Previous works use a mechanism based on a winch wire release using a flat board [1-3] or spring compression and pneumatic extrusion [4-5]. Legged robots [5-6], and hoping robots [7-8] able to jump over obstacles have been reported. Jumping mechanisms using a spring board were introduced in [9-10]. However, their main tasks are not as sophisticated as to jump on stairs.

In this paper, we propose a new jumping robot using a linked leg, able to overcome an obstacle and jump on stair. It is capable of either jumping over an obstacle or jumping on to an obstacle such as stairs instead of climbing or crawling. Jumping height is adjusted by tilting the body which is driven by a motor. The robot motion is controlled by sensors and a camera which provide a stair recognition and safe landing after jump up and down, making the robot autonomous and safe. All control devices such as microcontroller, sensors, and wireless module are packed into the robot body, dedicating to small size and light weight.

2. JUMP MECHANISM

The spring is compressed to exert a releasing force on the robot body. The motor actuates a torque, delivering a force to the spring. To use less force on the motor and more force on the robot, a four-bar link mechanism is adopted (Fig. 1). Moreover, this link attached with two foot pads provides a stable motion when the robot moves on the ground.



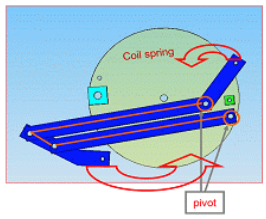


Fig. 1 Four-bar link mechanism for spring compression

2.1 Design of winch motor gear

The four-bar link is folded by wire-winding whose torque is generated by a winch motor. Winding and releasing a wire is operated by a single motor. To meet this ends, a partially cut gear was designed which is connected with a small shaft gear (Fig. 2). When the slip gear approaches the cut region, the shaft gear loose a contact with a slip gear, resulting in releasing the wound wire, which makes the compressed spring exert an instant force to the link pads, enabling the robot jump up.

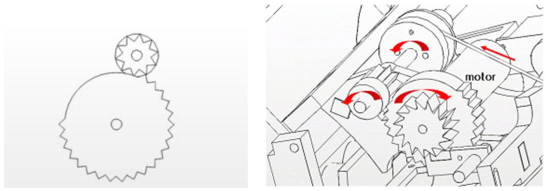


Fig. 3 Mechanism for winding and releasing wire

The jumping height is controlled by adjusting the tilting angle that is actuated by a motor. As the tilting angle increases the jumping height also increases. However, the horizontal distance has a maximum at 45 degrees. Therefore, an appropriate tilting angle considering the horizontal distance and vertical jumping height for overcoming the obstacle needs to be determined.

2.2 Control circuit design

The main controller is comprised with a DSP2406. 33 ports are used for a photo sensor, two ultrasonic sensors, two Zig-bee wireless communication modules, two terrestrial magnetism sensors, limit switch, 5 encoder motors, and two servo motors. Three A/D converter ports for two PSD sensors and temperature/humidity sensor are used.

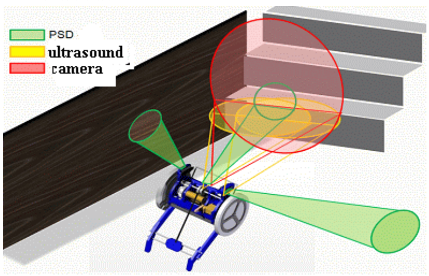


Fig. 4 Sensors for identifying a stair

As seen in Fig. 4, the front, left and right side of the robot are needed to be detected in order to jump up the stair or avoid an obstacle if insurmountable. To meet this ends, ultra sensors for the front (SRF-04), and PSD (GP2Y0A02YK) for distance measurement were installed. In addition, a temperature/humidity sensor, terrestrial magnetism sensor (compass, CMPS03), and gas sensor were included. On the other hand, four different motors were used: two encoder motors for travelling, a DC motor for winch winding, and a servo motor for adjusting tilting angle.

2.3 Operation algorithm

The robot motion mainly depends on the information the installed sensors deliver. In this system, three modes were programmed: travel, jump up, and jump down. The travel mode is constituted with an autonomous and wall-following mode. The robot starts its operation with a preset autonomous mode, being followed by a wall-following mode if an operation command is executed from the GUI (Graphic User Interface) program. The modes can be set by a remote operation as well and the jump up and jump down mode were implemented with the help of PSD sensor and ultrasound sensors.

2.4 Autonomous operation algorithm

As seen in Fig. 5, when the robot detects a wall during an autonomous mode, the robot changes to a wall-following mode. The method to detect a wall and to compensate an orientation which keeps the robot moving with a certain designated distance is introduced.

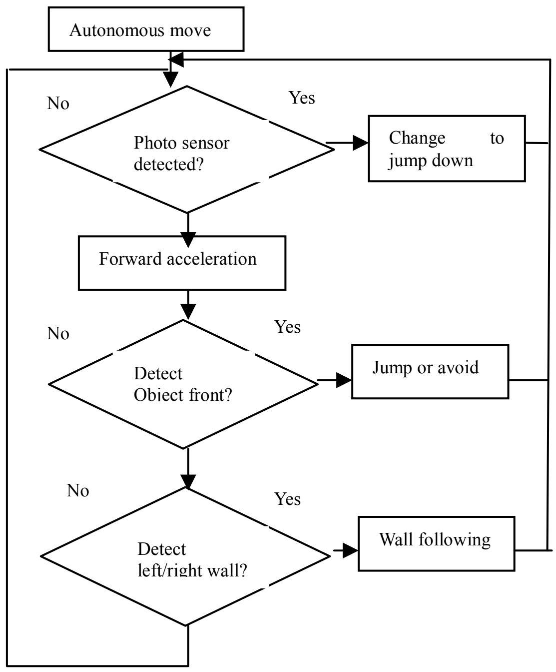


Fig. 5 Sequences of autonomous operation

2.5 Jump algorithm

While the robot travels autonomously, it may face an obstacle. Then a decision whether it jumps or avoids the obstacle based on the height of obstacle should be made. If the robot can surmount it, it tries to jump up. Otherwise, the robot should avoid it. If it is determined that the obstacle is a kind of stair, then the robot prepares for a stair jumping motion with the help of sensor information such as stair height, and alignment with a stair line. The height of the stair is determined from the PSD sensor which measures the stair edge height (Fig. 6). The PSD sensor, which is installed on the robot front body projects toward the front with 45^{o} angle. At this pose, the robot steps back from the stair frontage by 25cm which is exactly measured by two ultra sensors measure. With this setup, a stair edge lower than 25cm can be detected by the PSD. If not, the object is determined to be higher than 25cm, being insurmountable, which makes the robot detour. Once the robot determines to jump a stair, it needs to align with the bottom of stair edge to ensure a safe jump. The robot approaches up to 10 cm away from the stair with the help of two ultrasound sensors (SRF-04) which contribute to aligning with stair edge. It was proved with several experiments that the both sides of the robot front line must be 10 cm away from the stair bottom edge line to have safe landing on the next stair bottom after jump.

Once the alignment is done, the winch motor starts winding a wire, and compresses the spring. When the spring reaches the location where the gear teeth are cut, the spring automatically releases fast, exerting a jumping force to the robot body. Here, the jumping height is controlled by adjusting the tilting angle which is actuated by a servo motor. The current robot needs around 8 sec. to prepare for next jump. This time can be reduced by changing to a high speed motor.

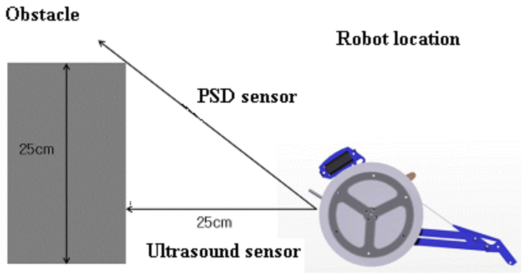


Fig. 6 Determination of height of object

The jumping down of the robot is as important as jumping up to ensure a safe landing. Without a sophisticated strategy, it is liable to fall down in a down mode due to a mechanical unbalance. To prevent this happening, sensor information, acceleration and deceleration adjustment, and an auxiliary mechanical device are required. The long-looking photo sensor detects the beginning of the stair edge line 15 cm ahead of the robot. Also, other photo sensors, which are looking at short distance, contribute to aligning the robot with the stair edge line (Fig. 7). After detecting the stair edge line and aligning the robot, the robot moves slowly forward to the edge line and starts jumping. At the same time, a supporting bar is placed on the robot front to prevent it from falling.

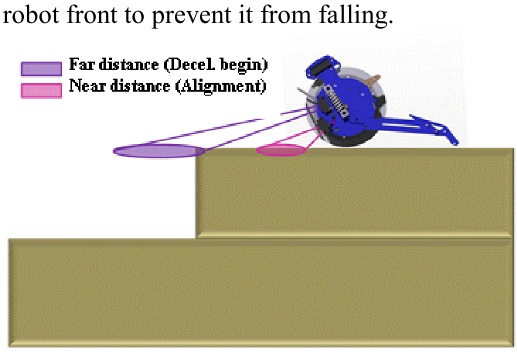


Fig. 7 Sensors data collection at jump down mode

2.6 Image Processing

The robot is designed to track a target using image processing techniques. The target is assigned by user's mouse-pointing on the monitor screen. The operation program is designed based on Visual C++ and all commands are transferred to the microprocessor embedded in the robot and all robot actions are monitored to the screen. Data are transmitted by a wireless Zigbee module and image is delivered to the computer via a RF wireless module. The target is assigned by an operator and the robot searches this target by adjusting the image with different threshold values for each R,G, and B color. Once the target is found, its center value and size are identified by using a basic vision processing. In Fig. 8 the searched target was proved to have 3309 pixels in magnitude and its center coordinates were (421, 243).

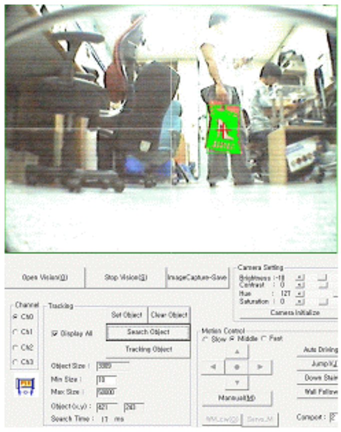


Fig. 8 Determination of target size and center

3. EXPERIMENT RESULTS

The developed robot was implemented at a real stair to verify its performance. The stair height for experiments is 19cm and the width is 1.5m. The success rate based on several trials was almost 90% for jump up and 95% for jump down. The failure was mainly due to not-complete alignment with stair edge line before jump. The maximum jump height was 25cm which is higher than normal stair, implying this robot can surmount any standard stairs in buildings. The stair identification by this robot sometimes fails due to unclear PSD sensor information, causing too long duration time for jump. More reliable sensor selection prevents from spending unnecessary time. Next, a target tracking is limited to a well-defined target in terms of a possibly single colored object and distinct shape. Including more sophisticated vision processing algorithms makes the robot more intelligent in terms of reducing target search time and increasing success rate of target identification. The sequential jumping motions for a stair are shown in Fig. 9. The pictures of the developed jumping robot are shown in Fig. 10.

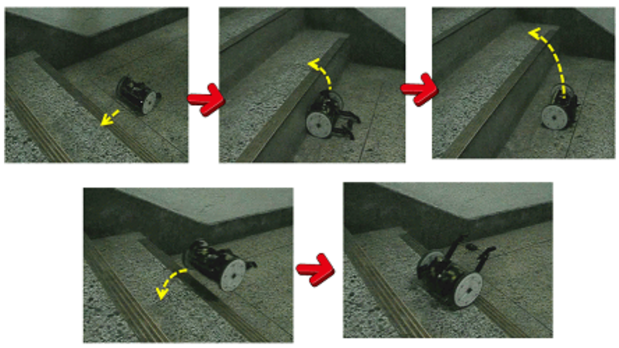


Fig. 9 Pictures of jumping sequences at real stairs

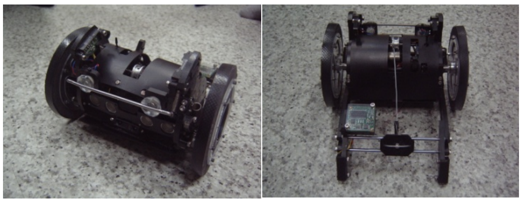


Fig. 10 Pictures of the developed jumping robot

4. CONCLUSIONS

A light and small sized but autonomous jumping robot was developed. It can autonomously move, avoid an obstacle, more importantly jumping up and down a stair. The wound wire stores spring compression energy, resulting in exerting a force to the robot body, and providing a jump motion. The 4-bar link mechanism, one way clutch, and special winch gear design makes the robot small, compact, and efficient. The total weight is around 900g and the size is 120mm (diameter) x 150mm (length), which makes a user handle with ease. A stair identification using sensors was successfully done, resulting in an autonomous movement. The maximum jumping height for this robot is 25cm which is higher than normal stair, making the robot have high success rate in jump up and down. A target tracking using a vision process was also implemented, dedicating to being employed to practical use such as a building monitoring robot with the help of an autonomous movement and stair jumping.

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