Rolling Locomotion with Spiny Multipedal Robots

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***Abstract*— Gemetric structures is an alternative frame for robotic locomotion as well as animal-inspired structures. We propose a spiny multipedal robot consists of multiple linear actuators as the legs. We developed a unique telescopic slide actuator that have a large stroke up to 200% of its minimum length. The default form of the robot is sphere with variable diameters. The radial arrangement of the telescopic slide actuators allows large rang of shape changing. We first show a basic properties of the actuator to verify the capabilities to elevate and propel the body. The single acatuator have the weight of 0.4kg and can support 4kg load maximum. We demonstrate that the robot with twelve spines can change the shape to adopt to the level ground, wall, and step. Large stroke legs enables the robot not only to rolling locomotion but to step over obstacles.**

I. INTRODUCTION

Versatile locomotive system for uncertain rough terrains is one of the challenges of mobile robots. Multi-wheeled or multi-legged system is an approach for stable and robust locomotion. The rocker-bogie system with six wheels used for Mars rover allows wheeled vehicle to climb over obstacles[?]. The wheeled robot still have concerns about getting stuck on sand area or in a ditch. Multipedal robot with six Elastic wheelegs (curved leg as wheel) is also proposed for all-terrain mobility. These robots have an anisotropic body structure, therefore, the robot can not flip or move omni-directionally.

Researchers have been explore the potential use of deformable isotoripic (spherical) geometric structures for locomotive system. The tensegrity structure consists of rods and wires originally proposed as a static sturucture is used for reconfigurable rolling robots

despite the successfull result in simulation, one of the difficulties in tensegrity-based robot is implementation of dynamic long-stroke linear actuator. Unique soft landing ability of tensegrity-based robot as a planetary lander was reported because of its elasticity and deployable structure.

Locomotion by shape changing is one of the many forms of locomotion. such as the tensegrity, and polyhedron

A rimless wheel is also the one of the source of inspiration of this radial leg structure.

Locomotion of robots, which is driven by mechanical power based on mortars, wheels, caterpillars, and generally plays a key role to define its accessible region in our 3D world. For a long time, robots have been studied supposing to function in plane, stable, and information-rich environment, but recently, robots which have the function in extreme, dynamics, and information-poor environment are required. For example, mobile robots such as rovers for flexible exploration have been developing to work in the extreme environment on the earth and the other planets including Moon or Mars. Although current general robots have less features, to move on the non-plane, dynamic, and information-poor environment, new robots are assumed to perform efficient, durable and multi-functional.

To construct new robots, the deformable shape possesses an important view to adopt the information-poor environment with freely movement of irregular environments including rough terrain, and there are various approaches to develop mobile robots. For example, soft robotics and tensegrity have been proposed to tackle this problem[4]. Soft robotics performs a variety of different tasks to achieve the desired shapes and functions.An important principle in the design of soft robots is that they need to implement active sensing to exploit the large deformability and non-linearity of the soft body[1]. Recently, a soft robot with quadrupedal walking is sufficiently large and strong, compliant to carry all of the components required for untethered operation. Tensegrity robots have been discussed in the field of mobile robotics because tensegrity, of which structure is a characteristic design with connecting compressive isolated struts and a network of tensile cables, can make robots robust, compliant, lightweight and energy efficient[2]. These uniquely deformable robots are expected to have locomotion ability on rough and irregular terrains.

The deformable body is a common important view in terms of robotic locomotion since as we described soft robots and tensegrity robots above. Proposing systems with extra degrees of freedom that enables robots to adapt to and locomotion in complicated environments can provide a new capability to reach currently inaccessible regions[3]. Due to achieve mobile robots with extra degree of freedom, we focus on large extension actuators. In previous work of a crawling robot, which had extension actuators and was rolling around, an extension ratio tends to be about 2:1 because it was enough to allow a mobile robot to topple from place to place by moving its center of gravity. To provide more varied and efficient locomotion, a follow-on effort sought to develop a robot with struts of which has a 2:1 extension ratio over. Our proposing design is described which new features a number of improvements over previous robots.

In this paper, we present how to design a large extension strut, and the deformable robot rolling on the terrain with the experiments about mechanisms that composed the robot. We first show the main architecture of a robot based on a large extensible structure with wires and pulleys, and its characteristics, and perform the experiments to evaluate the potential of the robot that has the large extension actuators. Second, we explain the principle of crawling using robot body deformation, and we insist that how large extension ratio make useful about a mobile robot useful, efficient and robust. Then, we also discuss the characteristics of the proposed robot in terms of design freedom and contribution to the robot locomotion on the inaccessible terrain for robots. Finally, we show experimentally that the prototype of a tensegrity robot can crawl in the real situation.

II. Locomotive Principle

We illustrate the previous principle of locomotion by robot deformation and address the new principle by our approach. For locomotion robots, changing in gravitational potential energy by body deformation of robots is critical. There is a contact area between the robot and ground when the deformable robot stops on the one point stably in neutral robot state. Next, deformation of the robot body cause in gradient changes with gravitational potential energy by shifting its mass center when it moves. Then, it generates a moment of gravitational force around the area where the robot is in contact with the ground, and this moment allows the robot to roll on the ground until a new stable position is achieved. Successive deformation of the robot, which can be generated by actuators, enables a continuous rolling motion along the ground. However, this principle is not suitable for scalability for practical applications. Locomotion robots are often used in unpredictable areas which for instance include rough surfaces and staircases. In such situation, the size of locomotion robots becomes an important component in order to accomplish arbitrary tasks. Therefore, large extension ratio needs to be considered to adapt in various situations.

III. Telescopic Slide Actuaor

A. Design

Applying pulley model to actuators, we developed the design of liner actuator to achieve the large extensible robots. This approaches enables us to design what more simply, and the power transmission from motor to the whole actuators would become very efficient.

The power resource of what is completely linear motor. The actuator is extended completely by the translation of power by wires, and the actuator is contract completely by the translation of power by wires The of 3D model of actuators can be seen.

B. Implementation

The base core 1made by 3D printer sustains the whole robot actuator and has a shape with several clearing of mass reduction. Next follows the spacer 2, which holds the base 1, the slide rail 3 and the linear actuator 4. The slide rail 3 made of steels is the main body of this actuator, and plays a important role when extension because of its slide structure. The linear motors 4 are power sources at this actuator. To combine these linear motors with slide rail through wire and pulley enable us to control simply. The chosen linear motor was a L16-35:1 option R which can actuate by RC input signal. In fact, we used two linear motors to achieve high torque enough to extend and contract completely. The several types of component 5 are connected among slide rails, linear actuators through pulley sand wires with some fixing bolts, and are made by 3D printer depending on its each shape of part to be connected. The wires 5 and the pulleys 6 are used to support movement of slide rail and to transmit power efficiently. A rubber sphere ball 7 is mounted at the end of the actuator to prevent the robot actuator from slipping on the kind of surface.

C. Basic Performance

To evaluate the potential of this actuator as a sufficient actuator for locomotion, we tested stiffness of the actuator structure.Since large extensible linear motion is generated is an essential property for achieving desired motions, we conducted preliminary experiments about its stiffness. We also present physical applications of Podilla acting as a rolling robot.

IV. ROBOT APPLICATION

A. Shape

The deformable robots adopted to extreme environments are mostly based on the three-dimensionally symmetric structure because it is better structure to cope with several kinds of terrain physically. For instance, the spherical rolling robots have a great potential benefit for the kind of robot locomotion. Then, we focused on a shape of regular dodecahedron because a dodecahedron shape is simpler than a spherical shape to manufacture. Our robot has radially 12 actuators on each face of dodecahedron in its center, and these features of the symmetric structure including regular dodecahedron allow the robot manage a wide range of situation when the robot collisions something and turns over. Additionally, the robot actuators with enough large extension ratio execute when the robot collisions with some obstacles.

B. Implementation

We built an Arduino-based control circuit to this robot to develop higher level of manipulability and programmability. Each of robot actuator is controlled by PCA9685 is an IC-bus controlled 16-channel. This micro controller governed when to extend/contract which robot actuator by using PWM signals.

V. Discussion

The future works with our design is that the payload is limited because the mechanism of this mobile robot depends on extension and contraction with a single or a few actuators. In case of untethered robotic locomotion, Podilla can move itself by deforming shape with enough sufficient performance, but it may be not enough while locomotion with something on it. When the actuators are needed more powerful and longer locomotion, their payload capability must be considered about the additional weight of battery. We hope to approach these challenges in future work.

Another important work in future with our robot is the topology of robots with actuators. Although we applied dodecahedron structure to mobile robotic structure with twelve actuators, we consider that there is some variation of structure to use large extensible actuators depending on several situations. The feature of actuators we presented is large extension, so this can be combined other robotic structures such as tensegrity robots.

A third future work is about the sensitivity of the exposed circuit including micro controller and batteries on the center of the robot. It is the best way to encase them in the regular dodecahedron block. However, the bottleneck is the batteries in terms of trying shrink the volume of circuit because batteries are required in case of untethered mobile robots. The technically approach may be to replace the linear motors with more efficient power source acting with less volume of battery.

We have presented a deformable robot with large extensible actuators. The large extension of actuators enables deformable robots to move around not-flat terrain, and expand the range of the application of mobile robots. Then, the design of actuators with pulley model can be used simply and completely to achieve actuators extended. Podilla that possess the dodecahedron base architecture with 12 actuators can perform greatly 1:3 extension.

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