Robotics and Autonomous Systems 62 (2014) 38–45

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

Impact reduction mobile robot and the design of the compliant legs

Teeranoot Chanthasopeephan [a,*], Arnas Jarakorn [a], Pongsakorn Polchankajorn [b], Thavida Maneewarn [b]

[a] Department of Mechanical Engineering, King Mongkut's University of Technology Thonburi, 126 Prachautit Road, Bangmod, Tungkru, Bangkok, 10140, Thailand

[b] Institute of Field robotics (FIBO), King Mongkut's University of Technology Thonburi, 126 Prachautit Road, Bangmod, Tungkru, Bangkok, 10140, Thailand

ARTICLE INFO

Article history:
Available online 8 August 2012

Keywords:
Impact reduction mobile robot
Compliant legs

ABSTRACT

In most mobile robots, the ability to move from point to point in various types of terrain was the most crucial part to the design. Being able to survive through impact conditions is also essential for robots under hazardous circumstances such as rescue robots or military robots. In this paper, we designed and developed a robot with impact reduction mechanism which is based on the compliant design of its legs. The stiffness of the legs was designed to not only to serve walking purposes but also to help reduce the impact while dropping. An experiment was set to investigate how the radius of curvature of the connecting plate and the compliant leg of the robot play a role in impact absorption. The radius of curvature is one of the key factors which vary the stiffness of the compliant parts. With this design, the robot will gradually press the ground during landing using springlike legs. The compliant legs with nonlinear spring constant help absorb impact energy while the robot hits the ground. During drop-landing motion, the robot also transforms itself from a spherical shape into a legged robot while landing. The legs are extended into a walking mechanism on uneven terrain and retracted to create a ball shaped robot for rolling motion over smooth terrain. The transformation between the spherical shaped robot and the legged robot increase its motion capabilities under various conditions including falling, rolling and walking.

1. Introduction

In the present day when natural disasters such as earthquakes and tsunamis occurs in many places around the world, there are needs for using robots to assist humans in survey and rescue operations. After a building collapses, robots can be sent in instead of humans for surveying the environment, whether it is safe for a rescue worker to go in. In this situation, a robot that can be easily dropped into a small opening, which also has the ability to continue navigating in difficult terrain would be useful [1]. The ability of a robot to function and maintain itself after going through these harsh conditions are essential. Military robots such as the Eye Drive by Northrop Grumman can be dropped, rolled, and thrown for surveillance purposes. The robot is considered a rigid body; while undergoing a dropping motion, the rigid body impact on the ground could essentially damage the robot including the electronics parts. Unless using high strength materials, having an impact reduction mechanism is required for the above mentioned situation.

To reduce impact, [2] studied extensively on the compliance requirements for legged locomotion. Stiffness of the leg was taken into consideration due to the advantages in maintaining energy during motion in a legged robot [2–5]. Under dropping conditions, the potential energy is converted to kinetic energy while the spring legs help absorb the energy in the form of stored strain energy. Springs were used to avoid excessive impact forces and at the same time keep the fluctuation of the internal kinetic energy [5]. Marhefka and Orin [6] analyzed the nonlinear compliant contact model in dynamic simulation. The model example demonstrated in the paper is for foot contact.

Impact in general is defined by the coefficient of restitution "*e*" which is determined by the ratio of the impulsive force during deformation and recovery. The value of "*e*" is approximated for linear elastic materials. The advantage of using a compliant leg is to absorb the impact energy and hence reduce the impact force on the robot's body. This value of "*e*" also depends on the property of the materials that come into contact during impact. Bi et al. [7] and Roberto et al. [8] created a spring-load inverted pendulum model to study dynamics of the compliant legged robot during impact and locomotion. The multiple impacts and vibration were then determined based on the model. To design a good impact absorption leg, we therefore have to take into account the material which is appropriate for walking and at the same time benefits our impact reduction mechanism of the legs.

Previous studies show the stiffness of the legs in passive running and walking [9–11]. The RHex robot [12] used a C-shaped

* Corresponding author. Tel.: +66 86 789 7120; fax: +66 2 470 9111.
E-mail address: teeranoot.cha@kmutt.ac.th (T. Chanthasopeephan).

0921-8890/$ – see front matter
doi:10.1016/j.robot.2012.07.017

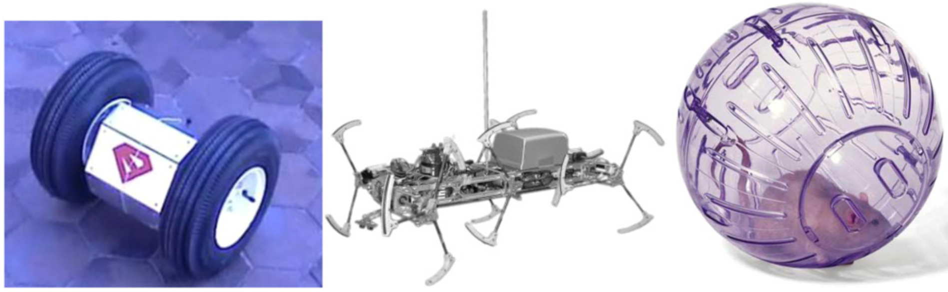

Fig. 1. Combined concepts for IRR (a) high impact survival robot [16], (b) whegs wheels robot [19], and (c) spherical robot.

leg in which stiffness could be adjusted during its motion through a designed controller. Walking and running with variable stiffness were considered difficult. Seyfarth et al. [13] and Geyer et al. [14] optimized walking speed through viscoelastic property of the leg after investigated the compliance and damping effect on human motion. Similar to that the MACCEPA [11] controlled the joint stiffness using servo motors for passive walking. The linear spring and torsion springs were used for creating a compliant mechanism of the leg for a dynamic walking robot. Galloway et al. [4] studied the dynamics of running of a legged robot by varying the stiffness of the legs. The slider mechanism was used to control the structure of the C-shape hence changing the stiffness of the legs during running motion. The motion based on the controlled stiffness of spring models in [4,15] are promising. While most work in the past focused on adjusting the spring stiffness of the linear spring, there is no study that discussed about the application of a nonlinear stiffness of spring in impact reduction of the legged locomotion.

In this paper, we design and develop a robot which can be dropped, rolled and walked. We combine the advantages of three robots found in previous work. The first robot mentioned here is the high impact survival robot [16].

The robot should be able to withstand high impact through throwing or falling on a rigid surface. This interesting mobility character of the robot is a great benefit for rescue robots or military robots when they are deployed by being thrown over uneven terrain. Fig. 1 shows the combined concepts of our robot. The first concept, Fig. 1(a) represents the high impact survival robot [16] where big wheels were used to protect the body of the robot and for motion. The disadvantage of this one is the lack of capability of overcoming obstacles. It is rather difficult to move over uneven terrains with two rolling wheels. The second advantage added to our robot are the whegs wheels [17] Fig. 1(b). The whegs wheels are good for walking up stairs, where the height of the stair is limited by the diameter of the wheels. The walking speed and faster motion like running can be developed later [13,18]. The disadvantage is that the robot's velocity is limited. The third part comes from the spherical robot Fig. 1(c). The spherical robot [19] uses an ''Inside Driving Unit'' (IDU) to drive the body upon motion. The benefit of the IDU mechanism is to increase the freedom of motion and the shell serves as protection to the robot's body. The dynamics model of a spherical robot was analyzed and presented a promising driving mechanism [20]. The disadvantage is the difficulty in overcoming obstacles or moving on uneven terrain. With combination of the three main characteristics mentioned above, our designed robot can be thrown during deployment, can walk on uneven terrains, and can be rolled on smooth surfaces for faster motion.

This paper consists of three parts, the first part corresponds to the IRR robot design and mechanism. We introduce the mechanism of the IRR robot with the self balancing part, the retracted–extended mechanism for the legs when the robot transforms between rolling and legged motion. The second part is the design of the compliant legs. The computational model of the spring like legs and how we determine the amount of energy stored in the spring legs of the robot upon impact. The last part is the simulation/experimental result and analysis of the impact reduction mechanism of the robot. An experiment was designed to study the effect of radius of curvature of the robot's leg and the connecting plate on the impact force at the robot's body.

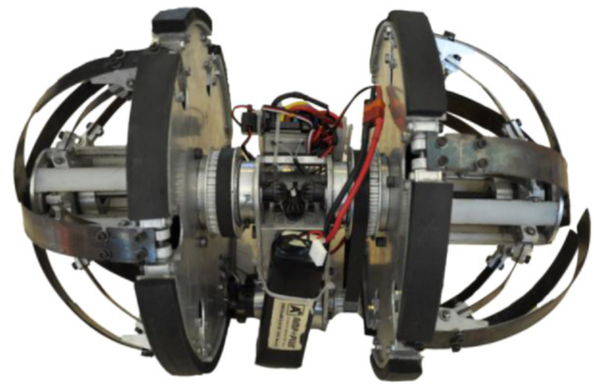

Fig. 2. Impact mobile reduction robot.

2. Design and mechanism

The impact reduction mobile robot (IRR) consists of two major parts which are the wheel and the body. The robot can be driven in two modes: rolling and walking. Another important aspect of the robot is the umbrella legs mechanism which assists the walking motion as well as reduces impact force during landing. The proposed umbrella legs mechanism combined with the c-shape non-linear compliant spring legs allows falling, walking and rolling motion of the robot to be performed using only 3 actuators with minimal control effort. Therefore, this design is very cost effective when compared with other type of robots such as a multiple legged robot or a balancing robot.

2.1. The pendulum self balancing body

The robot's body consists of electronic parts, batteries and motors as shown in Fig. 2.

The pendulum design (Fig. 3) allows the robot to self balance itself during landing. With this part, the robot will always land with the legs instead of the rear side.

2.2. The wheel

The wheel of this robot consists of impact reduction mechanism (i.e. the compliant legs), the retracted–extended mechanism and the driving wheels are shown in Fig. 2. The legs are designed using C-shape nonlinear compliant spring. This part is designed to support the robot during landing. The C-shape is chosen so that