2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics
Suntec Convention and Exhibition Center
Singapore, July 14-17, 2009

Design of A Three-Legged Reconfigurable Spherical Shape Robot

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***Abstract*— This paper proposes a novel mechanical design of a three-legged reconfigurable robot. In its dormant form, the robot is packed into a spherical shape for minimum storage volume. At deployment, the robot can be transformed into a mobile form of two interconnected hemispheres with three legs, each equipped with an omni-directional wheel. Feasibility of the transformation process was analyzed using a dynamic simulation in MSC.ADAMS. The construction of the robot has been completed up to the deployment of three legs, the lifting of the robot body, and the movement of omni-directional wheels. The deployment of robot legs is controlled using feedback control on five dsPIC30F2010 boards. The torque measurements of the transformation process are in good agreement with the results of corresponding dynamic simulation.**

I. INTRODUCTION

Robotic technology has become an integral part of human activities, from facilitating routine and precise production of industrial goods to performing hazardous tasks, such as scouting hostile areas or exploring uncharted space. The design of exploratory robot focuses on its flexibility and durability for working in unknown, often prohibitive environments.

In previous report [1], we proposed a novel robot design suitable for this challenging task. The proposed design considered a spherical robot in its dormant form: the spherical shape provides minimum packing volume for storage and transportation. The spherical configuration provides two additional advantages for deployment: (1) cushioning materials for impact upon landing can be conveniently installed on curved smooth surface of the robot, and (2) complex repositioning mechanism is not required for landing.

Because the maneuverability of the spherical robot is limited due to complex steering mechanisms, the robot is designed to be transformable into a mobile configuration with two interconnected hemispheres and three legged-wheels.

This paper further explores the feasibility of the proposed robot design by constructing the robot, developing a control circuit for robot movement, and measuring relevant parameters of the transformation process. Reviews of existing works on spherical robots are discussed in Section II. A detailed description of the robot design is presented in Section III. Design of control circuit is presented in Section IV. Experimental measurements of governing parameters in the transformation process are compared to the dynamic simulation in Section V.

This work is supported by Faculty of Engineering, King Mongkut's University of Technology North Bangkok

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II. BACKGROUND

The rolling sphere is considered to be nonholonomic. Nonholonomic systems can be described as nonintegrable rate constraints resulting from rolling contact or conservation of momentum. Many robotic locomotion systems designed based on this concept, e.g., wheeled robots, spacecrafts and underwater vehicles, have been shown using tools from differential geometry [2].

In particular, the rolling of spherical robot on a flat plane has been the subject of a number of studies: the spherical robot is commonly propelled by an internal mechanism with a single wheel resting on the bottom of the spherical shell [3], [4], [5]. A design proposed by Alves et al. [6] utilized the movement of the center of gravity of the spherical shell for steering, while a design proposed by Koshiyama and Yamafuji [7] used two internal pendulums for moving its center of gravity.

Previous discussions on the steering mechanisms of the spherical robots illustrate the drawbacks of this design: the control algorithm is highly complex, and the maneuverability is limited by the steering procedure.

This paper proposes an alternative design for steering a spherical robot. Instead of controlling the rolling mechanism inside the sphere, the robot can transform into a mobile form with three omni-directional wheels. The wheeled configuration provides ease of control and movement in any directions whereas the three-legs can be utilized to climb upon uneven surface.

III. ROBOT DESIGN

We propose a design of a reconfigurable robot whose body consists of two hemispherical shells and three legs. The outer hemispherical shells are made of acrylic glass, selected for its durability and light weight, with a diameter of 300 mm and a thickness of 3 mm. The fully stretched length of the robot leg is 183 mm and the omnidirectional wheel has a radius of 50 mm. The total weight of the robot is approximately 5.0 kg.

Each robot leg consists of a pair of leg plates, two sets of motor mount and an omni-directional wheel. The leg plates were designed to conform to the curvature of hemispherical shell for packaging in the dormant form. Two motor sets - one for deployment of the leg, and one for driving the wheel - were mounted at the opposite ends of the leg plate pair, see Fig 1

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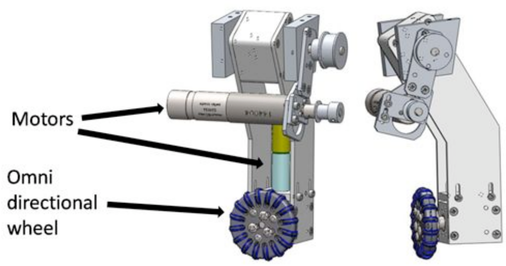

Fig. 1. Parts in Robot leg

Figure 2 shows the robot in its dormant form, and Figure 3 shows the robot in its transformed configuration. The outer shell was designed to accommodate internal control board, power source, folded legs, and additional space for mission-related equipments.

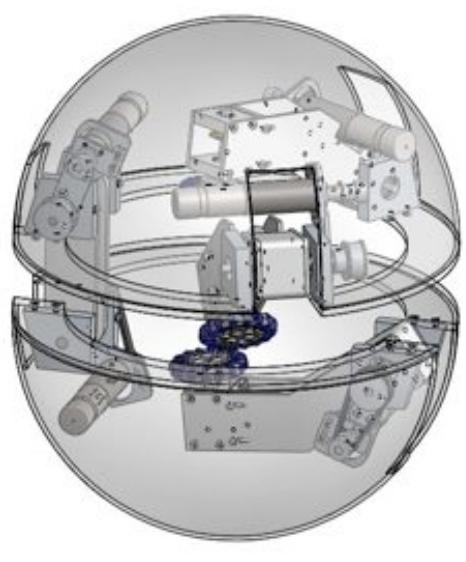

Fig. 2. Spherical robot in dormant form

An omni-directional wheel was attached to the driving motor. All three robot legs have identical design. Each leg is attached to the hemispherical shell by a segment joint and mounted on a flat cylindrical ring that serves as a structural support.

The transformation process is driven by a motor at each of the segment joints. When fully transformed, the robot legs can lift the robot body off the ground with a clearance of 2 cm. The hip joint of the legs can rotate for climbing, and the movement on flat surface is supported by the omnidirectional wheels.

Fig. 3. Reconfigurable Robot after transformation

IV. Control Architecture and Actuators

This work uses pulse width modulation (PWM) to control the motor movement. Each joint is driven by one motor. The motors for leg deployment are position-controlled whereas the ones for driving the wheels are speed-controlled.

The control system consists of one master controller board and four slave boards as shown in Fig 4. Each slave controls 2 motors. During the transformation process, the master sends a signal to the slaves through SS1 to SS4. The clock signal SCK synchronizes the output signal SDO via SDI. When one of the slave completes the task, the signal is transmitted back via SDO to the master through SDI port.

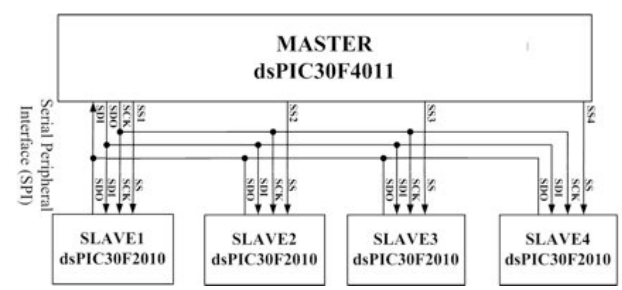

Fig. 4. Diagram of Master Slave controller board

Each control board is a 5V 16-bit dsPIC30F2010 running with an external crystal oscillator of frequency 7.3728 MHz and a x16 phase lock loop circuit. Fig 5 shows a schematic diagram of a slave board.

The controller dsPIC30F2010 sends out PWM and 2-bit motor direction via optoisolator, which drives 2 sets of L298N. The L298N circuit is also designed to protect over-current to avoid component failure. The L298N is selected because of its economical cost and local availability.

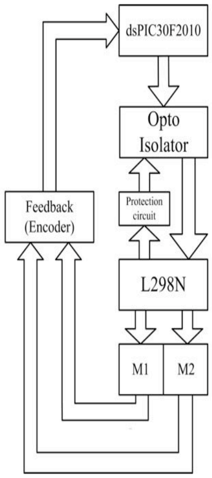

Fig. 5. Schematic diagram of one controller board

At this stage, the robot construction focuses on the leg deployment mechanism and the robot locomotion. A Maxon motor RE-max 21 (6 watt 24V) with maximum speed of 8920 RPM and a gear reduction ratio of 1386 to 1 is selected for the leg deployment mechanism, because it provides sufficient torque with low energy consumption. It also has a suitable dimension for the robot design with a safety factor of 2.0.

The robot motion is controlled via the driving speed of the omni-directional wheel. Here, a Maxon motor RE13 (3 watt 24V) with maximum speed of 13600 RPM and a gear reduction ratio 275:1 is chosen for its low energy consumption for prolonged running time.

V. Results

A. Simulation

Dynamics of the transformation process was investigated with the dynamic simulation software MSC.ADAMS. The analysis assumed that the robot had been fully transformed into a configuration of two interconnected hemispheres. The dynamic simulation was created for the leg deployment mechanism as shown in Fig 6.

The simulation prediction of the amount of torque required for leg deployment are plotted in Fig 7, Fig 8 and Fig 9 for the front leg, rear left leg, and rear right leg, respectively. The graphs show the torque profile when the legs are in contact with the ground.

The amount of torque required for deploying the front leg is approximately three times the torques required for deploying the other two rear legs. Note that because the simulation does not account for the effects of friction between leg-ground contact, some torques are required to hold the legs in place at the end of the deployment.

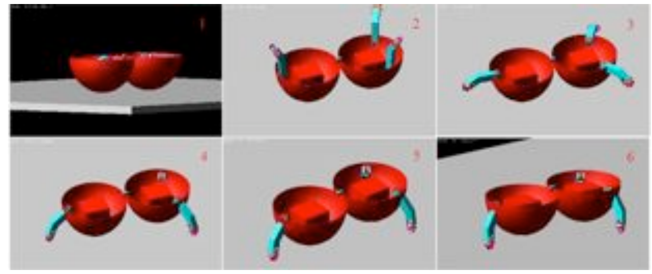

Fig. 6. Dynamic simulation of a reconfigurable robot

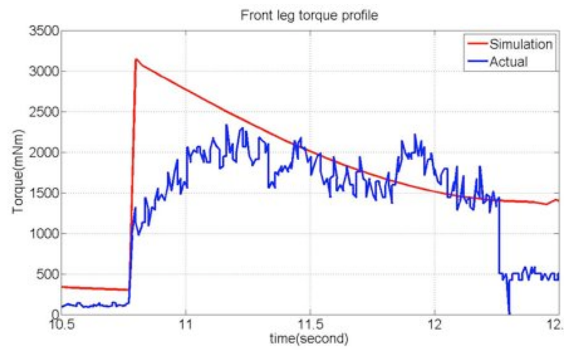

Fig. 7. A torque plot for deploying the front leg

The actual torques for the deployment mechanism were measured and compared to the simulation prediction. Generally good agreement between the predicted torques and the measured values confirms the validity of the robot design.

B. Experimental Results

The spherical robot has been built and the leg deployment process was photographed as shown in Fig 10. The experimental results show that the robot is able to deploy the three legs via a tethered control.

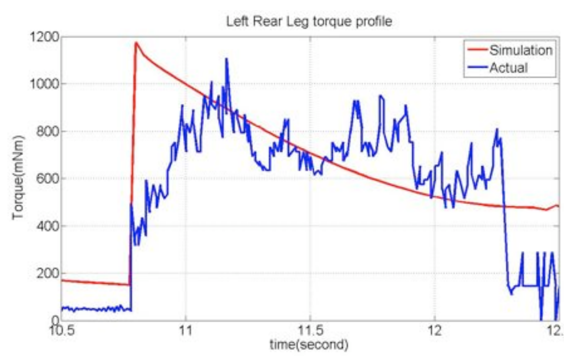

Fig. 8. A torque plot for deploying the rear left leg

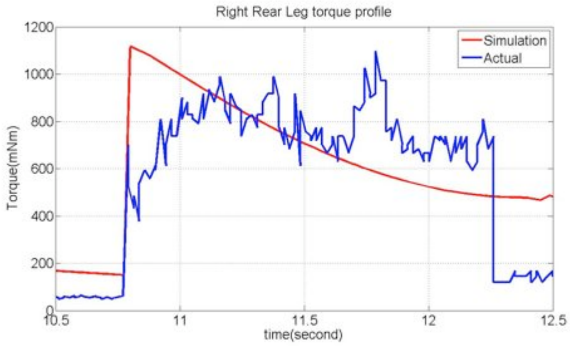

Fig. 9. A torque plot for deploying the rear right leg

Fig. 10. Experimental on the Reconfigurable Spherical Shape Robot

VI. CONCLUSIONS AND FUTURE WORKS

We demonstrated a mechanical design and control of a reconfigurable robot for exploration. The design requires the robot to be in a packed spherical shape for ease of storage and deployment. The robot may transform into a mobile form driven by omnidirectional wheel upon deployment. The transformation process and the leg lifting mechanism have been discussed and validated using dynamic simulation. The reconfigurable robot is currently under construction at King Mongkut's University of Technology North Bangkok. The robot shows good leg deployment mechanism under manual control. The next task is to develop the joint of the interconnected hemispheres and to install control system and power source on board.

VII. ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of Faculty of Engineering, King Mongkut's University of Technology North Bangkok for sponsoring this project.

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