Novel Foot Sensor Design for Legged Robots

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Abstract: There are many types of foot sensors (e.g., force and pressure sensors) available for legged robots. Most of them are expensive or have hysteresis effects. In this paper we demonstrate the design of a novel but simple and cheap foot sensor. The sensor uses a photo resistor and a light emitting diode enclosed in a 3D printed cylindrical assembly separated by a spring. The sensor's response can be adjusted by changing the spring stiffness. The sensor is based on a simple mechanism and uses a basic voltage divider circuit to obtain the output signal. Though the design of the sensor can be transfered to other systems, our initial design is targeted to the robotic toolkit, LocoKit, for monitoring walking behavior and detecting different types of surfaces.

Keywords: Foot sensor, Bio-inspired robotics, Legged robots, Surface recognition

1. INTRODUCTION

Advancements in artificial intelligence and machine learning have given robots the ability to compute and solve problems like never before. Robots have leaped forward from just programmed machines to machines with cognitive abilities and our robots are getting better by the day and smarter in crunching data to get more information out of the real world. To obtain this information robots are dependent on various sensory inputs like vision, touch, sound, etc. However some of the sensors are very complex and very expensive. They often require complex circuitry to obtain readings. In search of suitable foot sensors we were unable to find a suitable small, simple, and low cost sensor for our robotic toolkit - Locokit. Our search leads us into building a completely novel sensor with simple and cheap components. The sensor uses very little resources to obtain readings and requires a very simple circuitry. It consists of a light dependent resistor (LDR) and a light-emitting diode (LED) enclosed in a 3D printed cylinder that also holds the circuitry of the sensor. A test setup has been created such that the sensor could easily be tested on different surfaces. The robustness of the sensor was also tested on different types of surfaces. The advantage of using this sensor is that it is cheap and very easy to build.

2. RELATED WORK

Since legged robots came into existence, there has always been a need to fetch vital information from the legs of the robots to achieve better stability, control and maneuverability. To achieve this, most legged robots rely on the sensory information provided by the sensors installed in the legs of the robots. These sensors include accelerometers, gyroscopes, foot contact sensors, etc. Among these sensors, the foot sensor is highly used.

In this section, we will review the work related to foot sensors, of which the most common types of the sensor are strain gauges and piezoelectric sensors which measure force [6]. For exmaple, a biped robot, like entertainment robot SDR-4X II (QRIO) [3], uses four force sensors in its foot sole to achieve stable locomotion. Similarly, the biped robot BLR-G2 [8] uses three sets of strain gauges as a part of its foot sensor system. These sensors, however, have to be placed at a very precise place in order to obtain desired results. Additionally, these sensors require strong enclosures to protect them from external wear and tear. The flexible foot of the BHR-2 humanoid robot [4] uses a six-axis force sensor. The biped robot Meltran V [7], uses six-axis force-torque sensors to measure all the force and moments acting from the ground. These sensors are very expensive and not easy to use in various mechanical designs due to lack of flexibility. Some other types of foot sensor systems, like a 32 x 32 matrix scan type high-speed pressure sensor, have been developed and used [5]. This type of sensors is good to work with robots with large foot surface areas but it is not suitable for robots with a very small foot surface area, like the Locokit (Fig. 1). The HyQ leg [2] uses spring in the foot sensor. The spring compression is measured with a linear potentiometer, which helps it to calculate an estimation of the ground contact force based on Hooke's Law. The biped robot Meltran II [1] uses an ultrasonic range sensor for measuring the ground profile.

In contrast to the mentioned foot sensors, our foot sensor proposed here combines a number of benefits. Our sensor consists of modular parts; so even if one part gets damaged, it can be easily replaced by the user. Due to its modular design, it can be built according to the size of many types of different legged robots. The sensor is also very easy to build as all the parts can be easily 3D printed. It is based on very basic electronic components, like photoresistor and LED which are simple and cheap. The sensor also shows high sensitivity and gives consistent measurements over time. It uses very simple circuitry to con-

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vert physical changes into an electrical signal which can be use to distinguish different surfaces (like floor, form, sponge).

3. THE LOCOKIT ROBOT

LocoKit is a robotic toolkit optimized for a building light-weight, dynamic walking robot (Fig. 1). LocoKit provides a complete package for building the robot including mechanics, electronics, and software. It is very easy to work with and useful for research or educational projects. One of the key features with LocoKit is that it enables the user to build and start testing on the robot within an hour.

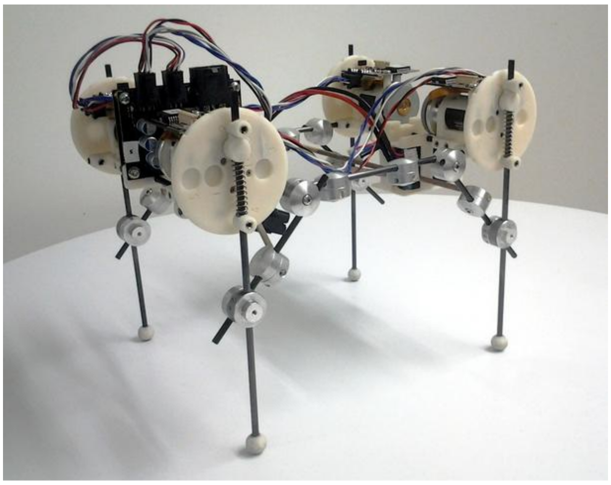

Fig. 1 The LocoKit-based dynamic walking robot.

4. FOOT SENSOR DESIGN

The sensor consists of 5 parts as shown in Fig. 2. Part 1 and part 3 hold the LED and the LDR, respectively. Both parts are enclosed in a hollow cylindrical chamber parallel to each other at a fixed distance when no force is applied to the sensor. Inside the hollow chamber, a spring is placed together with the LED and LRD. The spring can be exchanged so that the stiffness can be optimized to the weight of the robot. When a force is applied to the sensor, the piston (part 3 in Fig. 2) will be displaced inside the hollow chamber of the sensor (part 2 in Fig. 2). This displacement changes the position of the LED; thereby resulting in different intensity levels of light on the LDR, which can then be measured using a voltage divider setup.

The foot sensor works by measuring the change of received light proportional to distance between a LED and a LDR. If the distance between the LED and the LDR is small, the measured light intensity is high. In contrast, if the distance is increased, the light intensity is low. The change in light intensity can then be measured using the LDR. With this simple setup, the surrounding electronics needed to run this sensor is minimal. It only takes a standard voltage divider to read out the signal from the LDR, and the LED is driven from a 5V source through a current limiting resistor. During the test described in this paper, the sensor output (i.e., the change in light intensity) was transmitted to an analog-to-digital converter of a Arduino UNO [9]. The Arduino UNO features an ATmega328 microcontroller and delivers 10bit resolution (1024 steps).

Fig. 2 All parts were 3D printed. Part 1 and part 3 are shown in both the CAD model and 3D print.

4.1. Implementation on LocoKit

On LocoKit, the foot sensors have been implemented on all four legs as shown in Fig. 3.

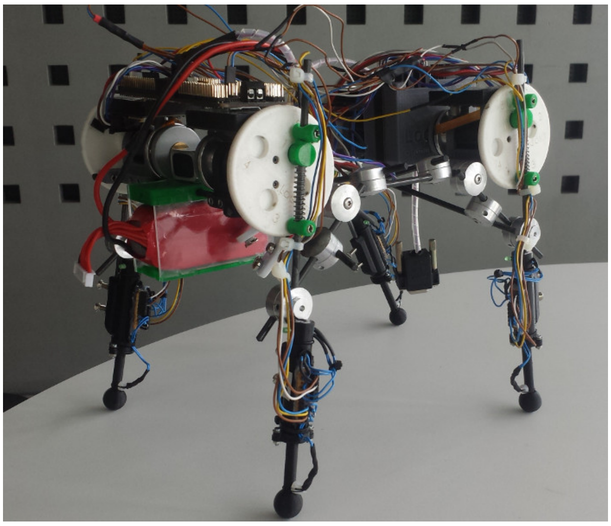

Fig. 3 The foot sensors implemented on LocoKit in an early mock-up version.

Currently the sensors are connected to an external board for measurements in preliminarily experiments to test their functionality on the LocoKit-based robot. Next step of the development is to have the sensors fully integrated into the electronics of the robot such that we can use the sensory feedback for adaptive locomotion control.

5. EXPERIMENTS AND RESULTS

To test the foot sensor, an electrically automated 3D printed test bed was built (Fig. 4). The testbed can lift and drop the sensor repetitively using a DC motor spinning with constant speed. The weight of the moving parts during the drop-tests is 100g. The moving parts include the sensor and the slider on which it is attached.

This experimental setup allows us to test the stability and robustness of the sensor with multiple repetitions. The sensors have been tested on different surfaces ranging from hard to soft.

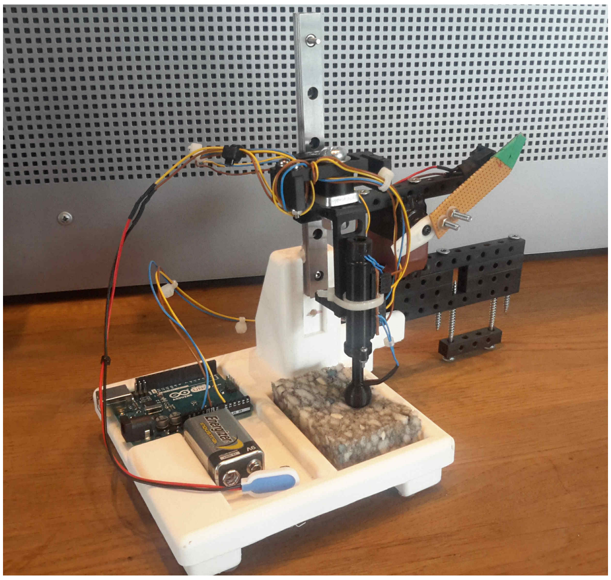

Fig. 4 Experimental setup of the foot sensor.

The signals shown in Fig. 5 are recorded from the sensor on different surfaces. The sensor was tested on 4 different surfaces, namely hard form, perforated foam, soft sponge, and the testbed itself which is made of plastic. Compared to the other three surfaces, the plastic is considered as a hard surface or material.

The measurements shown are the raw data from the test without any filtering or signal processing. Y-axes represents the voltage readout, which is proportional to the light intensity. With a know spring constant, the voltage readout can be directly converted to the force on the sensor using Hookes'Law.

Looking at the profiles of the four plots, two features on each plot is interesting, namely the first and second impact bounces. Looking at the first bounce, one can see that the harder the material, the larger is the first impact bounce - which is expected. The size and shape of the second bounce is also different, which can imply to the material property. The first impact bounce is just one peak of different heights, however the second differs more in height and width depending on the material.

What is therefore clear is, that the total profile of the four readings differs. This makes it possible to distinguish the four different surfaces/materials by using a classification technique, e.g., neural networks.

After having concluded the tests on the sensors ability to measure different surfaces, a long term stress test was run on the testbed, where the weight of the moving parts was increased to 300g which equals 1/4 of the LocoKit robot, and therefore is more sound when it comes to conclusions on stability. The stress test was run over 3 hours, resulting in 10800 drops. After this stress test the sensor was analyzed, and no trace of wear was found.

6. CONCLUSIONS

This paper presents the development of a novel foot sensor for legged robots. The sensor is composed of simple components such as a LED, a LDR, 3D printed parts, and a spring. Experiments conducted on the sensor shows its ability to measure the change in detected light. This gives information about both the static force and the force profile on impact. This information can give legged robots like Locokit the ability to distinguish different surfaces during locomotion.

As a first step here, we only focus on the design of the sensor and testing of the sensor. Our preliminary test shows that the sensor can be used to distinguish different types of surfaces/materials in a drop-test. Testing was done on materials like rubber, hard foam, and a sponge with stiffnesses ranging from soft to hard. In the next step, we will expand the functionality of the sensors by applying a neural network and adaptive algorithms which will enable the sensor to recognize the type of terrain on which the robot is moving. In future work, we will also integrate the sensors into the LocoKit controller boards, such that tests can be carried out on the robot and adaptive LocoKit locomotion can be investigated.

7. ACKNOWLEDGMENTS

This research was supported by Centre for BioRobotics (CBR) at the University of Southern Denmark (SDU).

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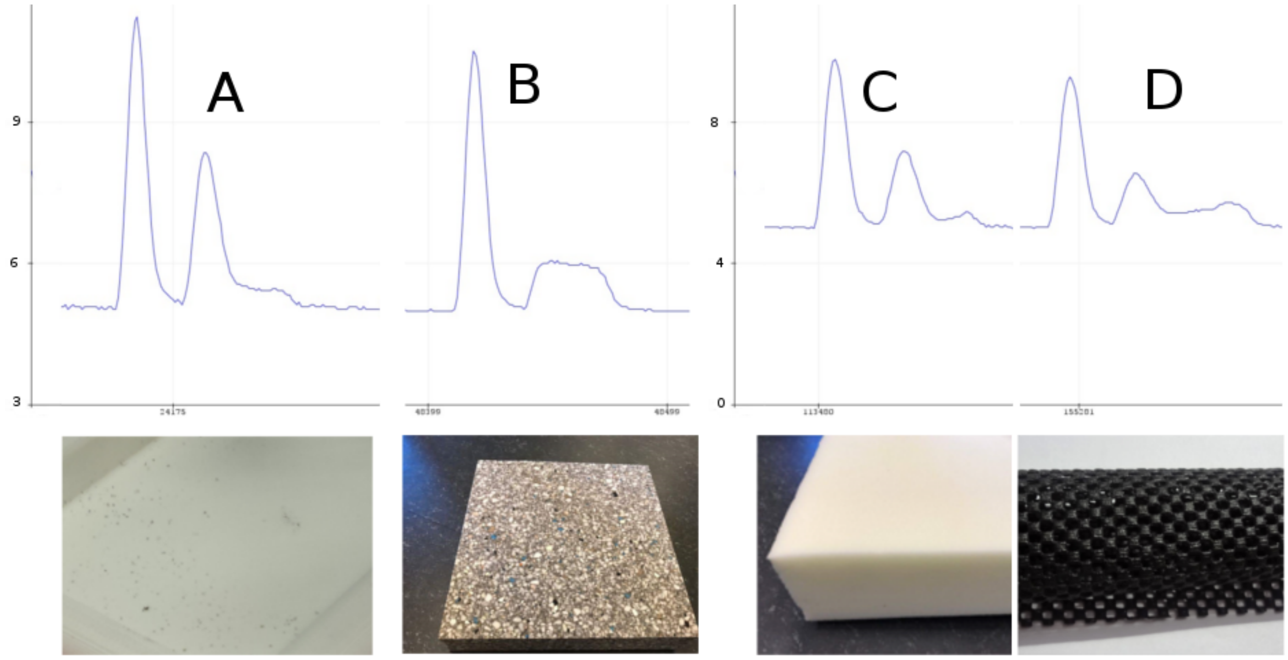

Fig. 5 The sensor's response from four different surfaces. A) Plastic. B) Hard foam. C) Soft sponge. D) Perforated foam. The four different materials give different profiles which can be used for surface/material detection. Y-axis is in Volt, X-axis is number of samples.

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