Scarabaeus: A Walking Robot Applicable to Sample Return Missions

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Abstract. Recently there was a growing interest in the applicability of walking robots for sample return missions especially in the context of space missions. Samples found in hazardous terrain are of particular scientific interest, especially walking robots have a high degree of mobility in such environments.

In this paper we present the six-legged robot Scarabaeus, which is prepared to demonstrate such a mission using its custom-made claw. We present the robot itself, the method of sample detection as well as the use of piezo-electric elements attached to the claw for the detection of a successful grasp.

1 Introduction

On the basis of their high degree of mobility especially in rough and steep terrain, there is a rising interest in using walking and climbing robots in space missions.

Sample return missions like STARDUST[1] or HAYABUSA[2] are also of scientific interest. Instead of sending humans on such missions, robots (1) can provide a better cost efficiency (2). A closer look at the advantages and disadvantages of legged robots (3) for planetary missions as compared to tracked and wheeled systems (see also (4)) shows that the former kind of robots could concentrate on retrieving a sample from an area which is difficult to access but near the robot's point of departure, where it may have been transported to by a wheeled rover.

When using walking machines for this task, a grabbing or collecting device is crucial. Walking machines offer a high degree of freedom in their legs. So it is self-evident to use a leg as manipulator. To manage space restrictions for sensors to detect contacts at the claw tips, we are using piezo-electric elements.

In order to study the feasibility of walking machines for this task, we constructed and programmed a six-legged robot called Scarabaeus (Fig.1(a)) as successor to the four-legged ARAMIES robot (5) and the eight-legged SCORION (6). All those robots are contolled by the same biologically inspired, behavior-based control concept(7; 8).

[1] http://stardust.jpl.nasa.gov/home/index.html
[2] http://www.isas.jaxa.jp/e/enterp/missions/hayabusa/index.shtml

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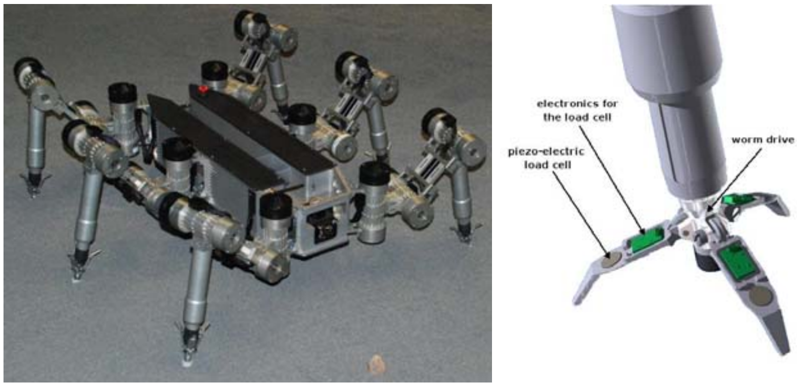


(a) The fully integrated Scarabaeus (b) Detailed description of the claw

Fig. 1.

2 Mechanics

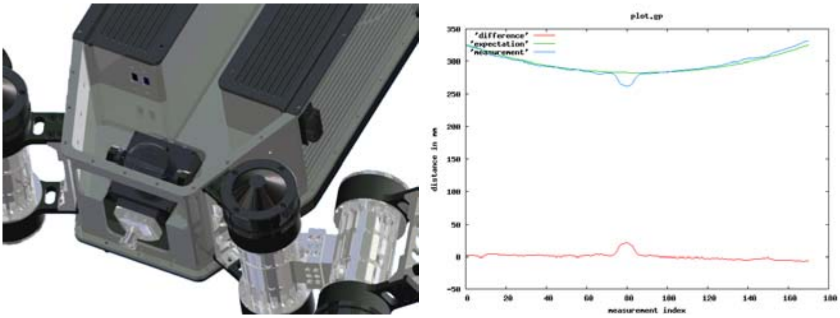
Each of the six legs has four actuated degrees of freedom. The first joint is directly connected to the torso and moves the leg along the body. The second one is used to lift and lower the leg. The third joint is used for the lateral movement of the lower leg. The last actuator is responsible for opening and closing the grabber which is attached to the end of the lateral segment (Fig.1(b)). A spring, which is integrated into the lower leg, is used to absorb shocks while walking and to counteract tensions between the legs.

The grabber consists of three claws which are actuated by a worm drive. These elements were developed to perform two functions: It is intended to avoid sinking into dusty surfaces by spreading the claws to enlarge the contact area and it provides the capability to use the legs, which innately have a large operating space, as manipulators.

3 Electronics

For the high-level computations an embedded PC with a 300MHz Geode Processor is used. The embedded PC is connected to a Motorola MPC565 microcontroller via serial connection (RS232) and to the user interface via ethernet (LAN or WLAN). The MPC565 is responsible for time-critical low-level locomotion behaviors like forward and backward walking, controlling the posture, and executing reflexes.

The MPC565 is controlling an FPGA which is responsible for the communication with the five Motor controller boards via Dual-Port-RAM. Each Motorboard is able to control six motors and to read in their sensory information. Thus the MPC565 writes the desired joint angles derived from the trajectory curves to



(a) Scarabaeus Head (b) Stone Detection Plot

Fig. 2.

the FPGA, and also reads the sensory information when it accesses the Dual-Port-RAM. The sensory information provided by the joints consists of position, temperature, and its required current in milliampere. A linear potentiometer is included to the spring-damped distal segment to measure its compression which indicates the bearing pressure and is used to sense ground contact. To detect whether a claw has contact with an object or not, each claw finger is equipped with a piezo-electric load cell which provides information about the gradient of the force applied to the material.

To select and track the object to be collected, the head (Fig.2(a)) consists of a visual module containing the Hokuyo URG-04LX Scanning Laser Rangefinder and a standard USB camera. It is actuated via a standard servo in order to rotate it around the pitch axis.

4 Control Software

The distinction of the low-level locomotion control and "highlevel" behaviors between two processors using a dezentralized behavior-based control approach is highly beneficial. The locomotion running on the MPC565 is independent of the processor load of the embedded PC which is responsible for i.e. obstacle detection, navigation and planning. Therefore the stability of locomotion is assured even in times of very high cpu load on the embedded PC system.

In our former projects, Bézier curves were used to specify the joint angles in a chronological sequence to generate rhythmic motion patterns like walking forward, backward, left, and right. Thus the Bézier curves are similar to the output of Central Pattern Generators (9). For the Scarabaeus we added an additional layer to the low level framework (10), which solves the inverse kinematic for each leg. Now the Bézier curves describe the endpoint of the feet in Cartesian coordinates, which still results in a rythmic movement pattern. By using these coordinates it was made easier to create new movement patterns because the developer could directly describe at which x-, y- and z-coordinate the feet should be at a certain point of time in the sequence. The ability to overlay different motion patterns such as forward and lateral walking to produce a diagonal walking persists.

Furthermore, it is possible to use this layer for the stone-collecting behavior to move the manipulator to the Cartesian object coordinates sent by the object detection.

5 Visual Object Position Detection

In order to detect a suitable stone for grabbing, an expectation value for the measurement of the laserscanner is computed (green line without amplitude in Fig. 2(b)[3]). A fitting difference (red line with positive amplitude) between the actual measurement (blue line with negative amplitude) and the expectation indicates a suitable stone to be collected as a sample.

Only when a suitable object is found, Cartesian coordinates are computed and sent to a collecting behavior within the low level framework running on the MPC565, which then takes care of grabbing the stone using the claws and placing it into a storage container on its back.

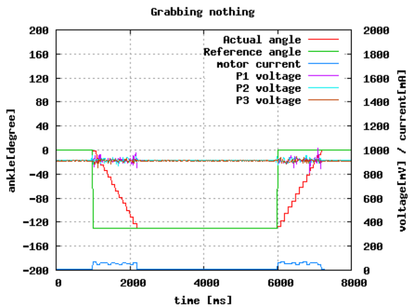
As opposed to other object recognition methods for detecting grabbing objects (i.e. (11)), our method has very low computational costs.

6 Tactile Object Contact Detection

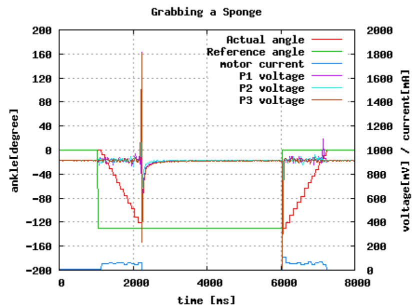
To collect a sample it is necessary to detect whether an object was grabbed or not. The usage of piezo-electric elements for manipulation is an approach to provide tactile information without the need to use very specialized sensors as decribed in (12).

To determine whether the sensory data provided by the grabber are useful to detect if an object was grabbed or not, several experiments were performed. In the first one, the grabber was closed without grabbing anything in order to get information about how strong the deflection of the piezo-electric load cells is as a result of the vibration of the claw motions. It showed that there were negligible voltage amplitudes of the piezo elements (Fig.3). The other experiments were conducted to analyze whether it is possible to detect the grabbing of hard and soft materials and whether it is possible to distinguish between them. One of them was using a sponge, the piezo-electric elements showed a high amplitude when the object was contacted and released. In the other experiment using a stone, the power consumption of the motor increased because it was not able to reach the desired position due to the fact that the stone was too hard.

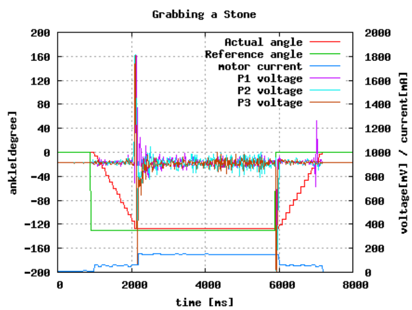
[3] The plot was taken when a one cm high object was in the scanline with an angle of about 45^o.



(a) Grabbing Nothing



(b) Grabbing a Sponge



(c) Grabbing a Stone

Fig. 3. Test results of grabbing detection. P1, P2, and P3 are the sensor values of the piezo electric load cells of the three claws.

7 Conclusion and Outlook

In our work we proved the usability of walking robots for sample return missions. We showed that it is possible to use the komplex kinematic of a leg which was extended with an additional grabbing device to take up a sample and place it into a container on the back of the robot. Thus there is no need to add a complete manipulating device to the system to perform such a task. In addition we showed that the task of stone collecting can be accomplished by methods with very low computational costs.

The piezo-electric load cells which are integrated in the claws can be used to detect whether an object was grabbed or not. The data on the power consumption of the motor can be used to get an idea about the stiffness of the material.

The use of piezo-electric load cells is a satisfactory way when the available space for sensors is constrained. Their use to control the motor current to allow tactile manipulation of objects is only one possible application. Also ground classification should be possible, if their amplitude is evaluated while the claw is spread and sinking into the subsoil.

Bibliography

[1] Schenker, P.S., Huntsberger, T.L., Pirjanian, P., Baumgartner, E.T., Tunstel, E.: Planetary rover developments supporting mars exploration, sample return and future human-robotic colonization. Autonomous Robots 14(2-3), 103–126 (2003), http://www.springerlink.com/content/g55m107335658367/fulltext.pdf

[2] Coates, A.J.: Limited by cost: The case against humans in the scientific exploration of space. Earth, Moon, and Planets 87(3), 213–219 (1999), http://www.springerlink.com/content/v624w0uv3p815705/fulltext.pdf

[3] Silva, M.F., Machado, J.T.: A historical perspective of legged robots. Journal of Vibration and Control 13, 1447–1486 (2007), http://jvc.sagepub.com/cgi/reprint/13/9-10/1447

[4] Patel, N., Scott, G.P., Ellery, A.: Application of bekker theory for planetary exploration through wheeled, tracked and legged vehicle locomotion. In: Proc. of Space 2004 Conference, pp. 1–9 (2004), http://aecoms.com/Documents/Space2004%20Paper%20(Final%20Rev'd).pdf

[5] Hilljegerdes, J., Spenneberg, D., Kirchner, F.: The construction of the four–legged prototype robot aramies. In: Proceedings of CLAWAR 2005, London, UK (September 2005)

[6] Spenneberg, D., Kirchner, F.: Scorpion: A biomimetic walking robot. In: Robotik 2002, VDI, Ed. VDI, 2002, vol. 1679, pp. 677–682 (2002)

[7] Spenneberg, D., Strack, A., Zschenker, H., Kirchner, F.: Reactive leg control for four–legged walking based on cpg and reflex models. In: Proceedings of the 9th International Conference on Climbing and Walking Robots (CLAWAR 2006) (2006)

[8] Spenneberg, D., Strack, A., Zschenker, H., Kirchner, F., Hilljegerdes, J., Bosse, S.: Control of a bio–inspired four–legged robot for exploration of uneven terrain. In: Proc. of ASTRA 2006 Workshop, ESA–ESTEC, Noordwijk, NL (2006)

[9] Hooper, S.L.: Central pattern generators. In: Embryonic ELS (2001), http://crab-lab.zool.ohiou.edu/hooper/cpg.pdf

[10] Spenneberg, D., Albrecht, M., Backhaus, T.: M.o.n.s.t.e.r.: A new behavior–based microkernel for mobile robots. In: Proceedings of the ECMR 2005 (2005)

[11] Recatalá, G., Chinellato, E., del Pobil, Á.P., Mezouar, Y., Martinet, P.: Biologically-inspired 3d grasp synthesis based on visual exploration. Autonomous Robots (2008)

[12] Melchiorri, C.: Tactile Sensing for Robotic Manipulation. Lecture Notes in Control and Information Sciences, vol. 270, pp. 75–102. Springer, Heidelberg (2001), http://www.springerlink.com/content/hqfu29l9d4k0g7b1/fulltext.pdf