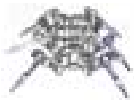
Scorpion – outdoor-capable walking robot

Dipl. Inf. Dirk Spenneberg
Robotics Group
University of Bremen

Universität Bremen
www.Informatik.uni-bremen.de/robotik



The "SCORPION"

The focus in the "SCORPION" project is the development of a bio mimetic eight legged outdoor-capable walking robot. A possible future field of application for robots based on legged locomotion is the work in dangerous, highly unstructured, rough and unpredictable environments, where mobility is critical, for example search and rescue missions in collapsed buildings. The mobility of present wheeled and also tracked vehicles is too limited for such tasks. Therefore it is essential to develop better means of locomotion.

The "SCORPION" project deals with building an eight legged all-terrain robot, which is controlled by an bio mimetic control approach. The control of these robots is based on models of two biological control primitives: Central Pattern Generators and Reflexes. The Central Pattern Generator Model is controlled from a higher central control level by means of Rhythmic Motion Patterns (RMPs) and posture control primitives (PCPs). With this approach omni directional walking and a smooth and fast crossing between different motion patterns is possible. Additionally the posture and the speed of the robot can be changed while walking. The robot were successfully tested in rough, sandy and rocky terrain. One copy of this robot is currently tested at the **NASA Ames Research Center**.

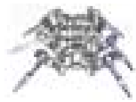
Technical Data

The "SCORPION" has eight legs and measures 65 cm from front to back. The width depends on the posture of the legs and varies between 20 cm and 60 cm. In a typical M-shape walking position the robot is 40cm wide. The robot weights 11.5 kg including the 3.0 Ah batteries.

Each leg has 3 degrees of freedom, a thoracic joint for protraction and retraction, a basal joint for elevation and depression and a distal joint for extension and flexion of the leg. The joints are actuated by 24V, 6W DC-Motors. The leg also features a spring element in the distal segment to reduce the mechanical stress and for measuring the ground contact force by an integrated linear potentiometer. The robot senses the following proprioceptive information: the position of each joint, the amount of current drawn by each motor, the tilt in 2 dimensions (pitch, roll) and the load on each foot tip. Furthermore it is equipped with a compass and a forward facing ultrasound distance sensor. For teleoperating the system and for acquiring data during an experiment, the system has a bi-directional communication link for video transmission with a PAL CCD camera and for data exchange between the robot and an external laptop with a communication and control interface. Thus it is possible to use the robot as a semiautonomous system.

The control hardware is onboard and features a Motorola MPC555 microcontroller and an XILINX Virtex E FPGA. The MPC555 is used for the processing of the non-leg sensors and for the behavioural control of the system. The FPGA is used for the processing of all leg-sensors (position and drawn current of each joint, foot-tip) and for the 20Khz PID-control of the joints.

to be continued page 2



The bio mimetic Control Approach

To describe the dynamics of such a system using a standard kinematical model (as used for industrial robotic arms) is very difficult. For a system with n degrees of freedom at least n coupled equations are needed. For rotary joints these equations are nonlinear. Computations with such a set of nonlinear equations are very complex, thus this technique is very unattractive for online computation in autonomous systems.

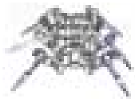
In contrast biological systems like spiders or insects are very well able to solve this complex nonlinear problem. Given the fact that they are using in comparison to current computers a comparatively slow computing nervous system, there must be other solutions to the problem of robust walking through rough terrain. Biologist have proposed different models in dependency of their experimentally gained data and observed animals. What all these models have in common is that they rely heavily on decentralized control. The control models can be divided in two main ideas. The first is control based on so called "Central Pattern Generators" (CPG) wherein the actuators are controlled by an endogen pattern produced by a central oscillatory mechanism. The second is reflex-driven control where, in contrast to the first one, the state of the actuator is only a function of the interaction with its environment. Both approaches have in common that they need only a low amount of computational power and thus are suitable for autonomous walking robots. A pure reflex based control acts only on the basis of sensory input, whereas the CPG-based control is able to produce rhythmic motion without the need of sensory feedback. Thus in case of false, unreliable or insufficient sensor data (e.g. at high speeds) the CPG-approach is more robust. On the other hand in a very unstructured and dynamically changing environment the endogen produced motion pattern might be highly inadequate.

Scheme of the Motion Pattern Control Approach

Therefore the control approach we developed for the "SCORPION" robot aims at using the best of both worlds. The idea is to have rhythmic motion behaviours (RMBs), which can be activated at different strengths by the central control level. The RMBs control the motion of the system like a CPG-based system when the disturbances from the environment are rather small. These behaviours simultaneously influence the amplitude and the frequency of the thoracic, basal and distal oscillators (OST,OSB and OSD). The oscillators are connected to a common clock which is used for local and global (in relation to the other legs) synchronization purposes. The oscillators output is a rhythmic signal which can be described with splined sinusoid waves. It describes the trajectory of the corresponding joint in its angle space. Thus it represents the desired behavioural motion, which is translated via the motoric end path into pulse width modulated (PWM) signals to drive the motors.

Inline with this rhythmic input to the motoric end path are a set of perturbation specific reflexes, which are implemented as 'watchdogs'. If greater disturbances are sensed these reflexes (e.g. a "Stumbling Correction reflex") are triggered and override the signals of the oscillators with precompiled motion signals to stabilize the system. The RMBs enable the system to move forward, backward and lateral and to turn with different radii. By activating more than one of these the RMBs' effects can be combined through a overlaying process. For example, if the 'move forward' and the 'move lateral left' RMBs are activated at the same strength the resulting motion is a diagonal forward motion to the left. The overlaying process ensures that the transition from one motion to another is a smooth and quick motion, thus ensuring that the system keeps stable. An advantage of this is that the change of the motion direction doesn't require to stop the robot first.

to be continued page 3



Universität Bremen

www.Informatik.uni-bremen.de/robotik

In addition to the RMBs the architecture provides the higher behavioural level with so called Posture Motion Behaviours (PMB) as means of control of the posture of every leg. For example the height and the tilt control behaviours on the central control level are using these PMBs to stabilize the system while it is walking. Again the overlay process combines the influence of the PMBs with the influence of the RMBs on the actuators. Thus it is possible to change the height of the main body, while walking, by just outstretching the legs. All these mechanisms together enable the system to walk at quite constant speeds through rough terrain. Thereby it is possible to walk with the same software architecture over a high variety of different substrates like rocks, sand, mud, grass, concrete and asphalt. Its maximum speed over flat terrain is half of a body length (30cm/sec). The system is able to overcome obstacles as high as a full outstretched "SCORPION" and it can climb up ramps up to 35% and still overcome small obstacles, like 8cm high pipes.

Furthermore the additional postural control, gives the user in addition to the rhythmic locomotion the exact control over every joint, which can be used for deliberative control. This can be used for a wide variety of interesting future behaviours, for example the posture of a single leg can be changed in the way that it can be used to carry simple objects on the back of the robot. We implemented and successfully tested a behaviour to grab a beam with one leg and then walk away with it on the remaining seven legs.

Other experiments have shown, that is it possible by only changing the posture of the system and using the unchanged RMB for forward walking, up-side down brachiation along a beam can be executed. The only difference between brachiation and forward walking in our approach is the activity level of the forward RMB on the legs and the posture of all legs.

Thus the locomotion control level provides the programmer with a simple but very powerful interface for locomotion control. For more information on the "SCORPION" robot please contact **Dirk Spenneberg** or take a look at the publications section.

More information, pictures and videos you will find at **www.roboter-info.de** .
Furthermore at the Web-Sites of University of Bremen:

http://ag47.informatik.uni-bremen.de/eng/project.php?id=4&details=ja

Co-Workers : Stefan Bosse, Jens Hilljegerdes, Florian Penquitt
Cooperations : NASA
Sponsors : DARPA and NASA