The Bipedal Robot

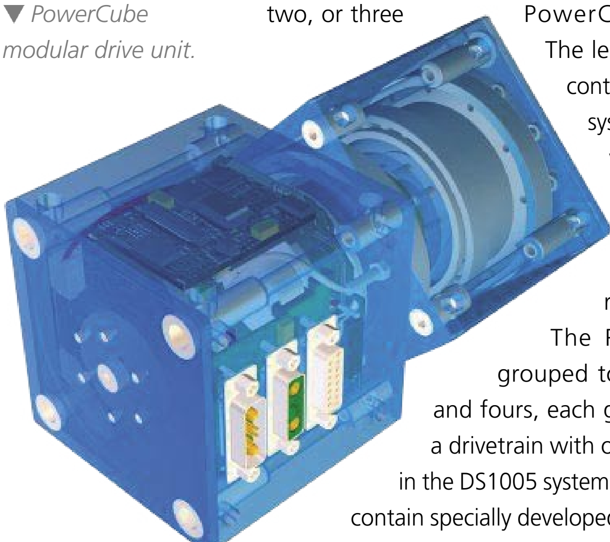
- **The University of Linz is using dSPACE hardware to develop a bipedal robot**
- **Control by dSPACE DS1005 PPC Board**
- **Walking speed of 0.5 km/h**

The University of Linz has been doing intensive research into bipedal walking for several years. The projects include developing new artificial legs and revolutionary drive concepts, and also a bipedal walking machine controlled by dSPACE hardware. The biped's joints are moved by DC motors with harmonic drive gears. The objective is to produce a completely autonomous robot.

Research into walking machines has increased greatly over the past few years. Walkers have the advantage over wheeled robots of being much better at maneuvering across rough and inaccessible terrain. Their potential uses include work in radioactive or chemically contaminated regions, which are extremely hazardous to human beings, and carrying loads on rescue expeditions in mountainous areas.

The Biped's Structure

The walking machine is 1.80 m tall and weighs 40 kg. It is driven by 14 PowerCubes from amtec robotics, a company in Berlin, Germany. These are compact rotary units consisting of electronic motors and play-free harmonic drive gears, with the entire electronics (control and drive) integrated. The biped was designed to mimic human gait. It has the same degrees of motional freedom as a human being, i.e., two directions of motion in the ankle, one in the knee, and three in each hip joint. Each joint therefore has one, two, or three PowerCubes in series. The legs are completely controlled by a DS1005 system from dSPACE, which communicates with the PowerCubes via a CAN bus at a rate of 500 kbit/s. The PowerCubes are grouped together in threes and fours, each group constituting a drivetrain with one CAN controller in the DS1005 system. The robot's ankles contain specially developed force-torque sensors based on strain gauges, which communicate with the dSPACE system via a microcontroller and an RS232 interface. The forces and torques are used to determine the zero moment point (ZMP), a parameter that is vital to stabilization. If the ZMP is within the foot area projection, the gait is stable.

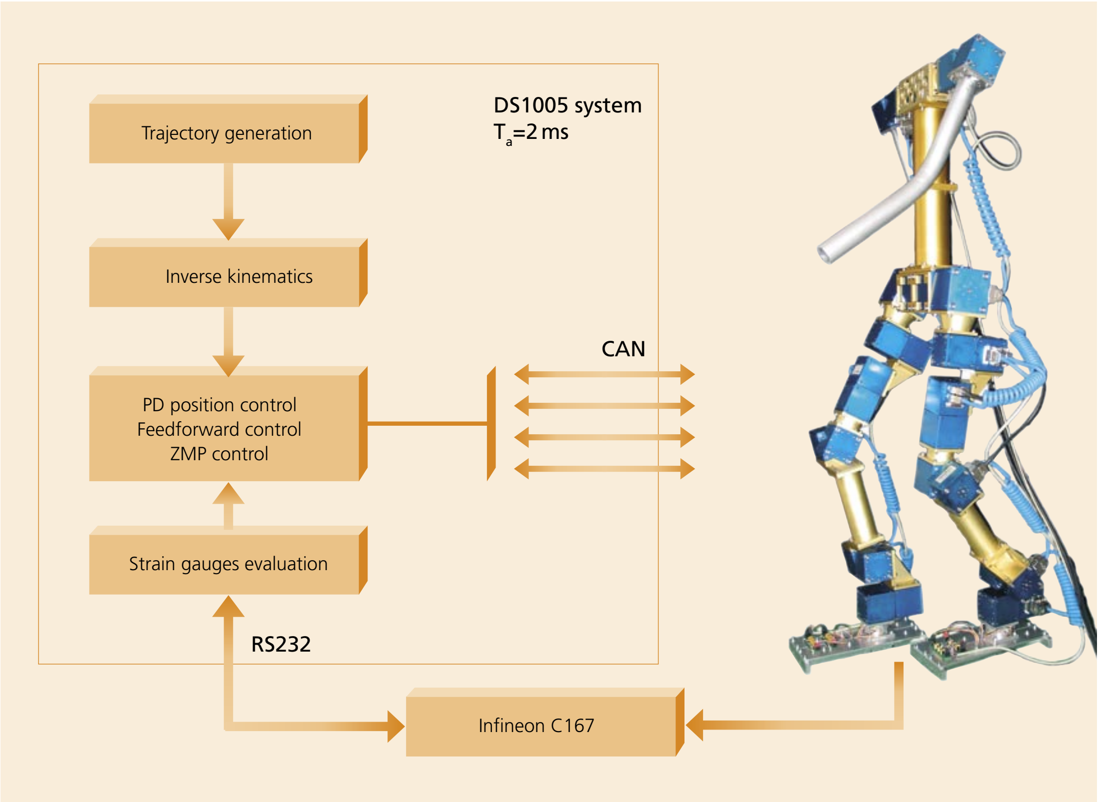


▼ *PowerCube modular drive unit.*

The Control Concept

The control was designed in MATLAB®/Simulink® and runs on the dSPACE real-time system. For maximum clarity of design, the sequence control was implemented as Statecharts in MATLAB/Simulink. All computations must be executed in real time.

- The control computations begin with the robot's current position and the direction in which it must move in 3-D space. The trajectory generator then uses this data to compute continuous trajectories for the hips and the two feet, expressed as positions in the inertial system and orientations in the form of Cardan angles. Calculation of the hip trajectories is based on an inverted pendulum, with an appropriate differential equation being solved to achieve a stable gait.
- The trajectories are available in world coordinates and converted into the biped's joint coordinates via inverse kinematics. Because of the way the legs are constructed, the inverse kinematics have no analytical solution and have to be solved numerically by Newton's method.
- The angles obtained from this are the input to the position control. This basically consists of a control with overlaid PD joint controllers. The control calculates the robot's entire forward dynamics during run time and compensates for gear elasticities. The PD control ensures that the joints are stable and equalizes factors such as imprecise parameterization and the effects of friction.



▲ *Schematic of the control concept: Communication between the dSPACE system and the force-torque sensors in the robot's ankles via a microcontroller and an RS232 interface.*

A ZMP controller is overlaid over the PD control to ensure stability of gait. The ZMP is given by the quotient of the relevant forces and torques in the ankles. The control system ensures that the ZMP stays within the convex hull of the foot areas.

High-Performance Real-Time System

All the calculations run at a sampling rate of 2 ms. The fact that the models are easy to modify has proven to be a decisive advantage. Our partners are two experts in the field of robotics, amtec robotics and dSPACE.

Outlook

The current implementation of the robot can reach a walking speed of 0.5 km/h. This speed will be increased in the coming months by extensions to the control concept. Additional sensors will also go into operation to scan the environment. The plan is to use two cameras that will perceive the three-dimensional environment in stereoscopic vision, enabling the robot to move autonomously.

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Glossary

Harmonic drive gear – Compact, lightweight transmission with a high gear ratio and high precision

Force-torque sensor – Sensor that evaluates the directions and amounts of effective forces and torques (for example, in the motion of a robot leg)

Zero moment point (ZMP) – Point at which all the forces and motion torques acting on the robot are zero

Trajectory – Computed path of motion