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Walking Robots – Vision and Locomotion

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The development of humanoid walking robots has been one of the great challenges faced by scientists and engineers worldwide for some decades. Recently, Japanese companies and researchers have reported on impressive advances in the design, construction, and stabilization of those artificial bipeds. This may lead to the conclusion that the principle problems involved in stable biped locomotion have been solved. More detailed analysis shows however, that robots are still far away from being able to show autonomous locomotion behaviour or even to move freely and in a goal-oriented way in environments made for humans.

Key capabilities for goal-oriented autonomous locomotion are visual environmental perception, and transformation of the gained information in safe step sequences. Until now, these issues have been only rudimentarily dealt with and imply investigations on the high level coordination of vision and walking. Activities of the research group *ViGWaM* (**Vi**sion **G**uided **V**irtual **Wa**lking **M**achine) at the Institute of Automatic Control Engineering (LSR) of the Technische Universität München, focus on this topic.

The main goal of the project, which is supported by the Deutsche Forschungsgemeinschaft (DFG) within the *Autonomous walking* Priority Research Program, is to enable a vision-guided biped walking machine to walk autonomously through a prototypical scenario scattered with various daily life obstacles. The robot perceives the environment using an active vision system comprising a stereo camera pair with view direction control. The acquired image streams are analyzed with fast image processing algorithms implemented in a distributed computer network. The visual information is then used for situation dependent reactive step adaptation and step sequence planning during walking.

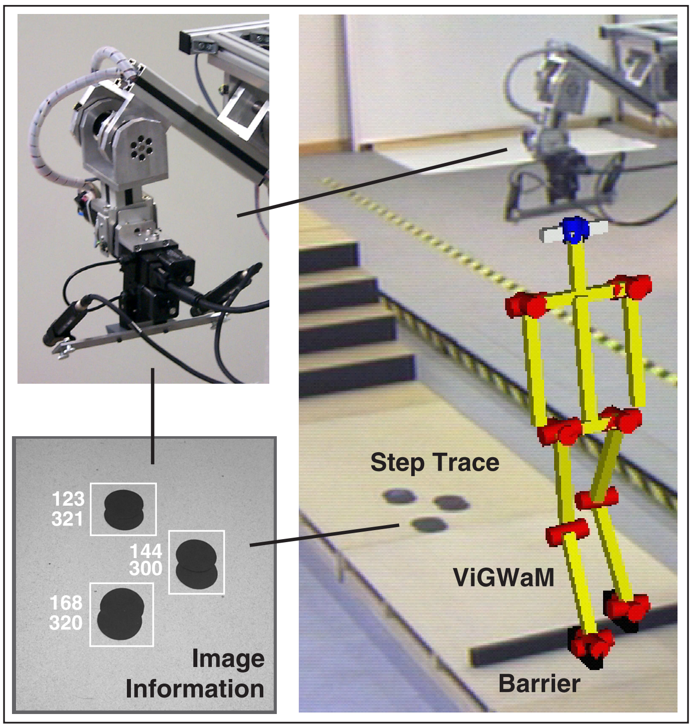

Figure 1: The Vision Guided Virtual Walking Robot *ViGWaM* steps over a barrier on its way towards a staircase.
Right: Illustration of the Hardware-in-the-Loop experiment with an animated simulation model of *ViGWaM* in a Computer Augmented Reality display.

Left up: Details of the agile pan-tilt head with the technical eye system mounted on a robotic arm for head motion emulation.

Left down: Results of camera image analysis for predictive step sequence planning and execution.

Theoretical investigations carried out in our group include methods for task-oriented adaptation of view direction, robust real-time obstacle detection, reconstruction, and classification, and predictive step sequence planning and execution. Investigations originating from biology and biomechanics on human vision and walking have been chosen as a basis for our research. The various methods developed converge on a common control architecture leading to an optimal solution integrating biology and technology.

For validation purposes, an emulation environment with Hardware-in-the-Loop, Virtual Reality (VR) and Computer Augmented Reality (CAR) components has been developed. This framework allows the validation and extrapolation of novel vision-based control approaches with respect to application on a variety of walking machines. The experimental results can be evaluated rapidly and efficiently. Furthermore, the integration of the technical eye system together with their intelligence on a physical walking machine can be prepared and accelerated. In the rapid prototyping environment, head and thereby resulting camera motions of a computer simulated walking machine are emulated in real-time and in a physical scenario, independent of specific walking machine hardware. The experimental emulation set-up combines head motion emulation of the dynamically stable *ViGWaM* using a wheeled mobile platform, a SCARA-type robot arm, and a pan-tilt head with a stereo camera pair. The motion behavior of *ViGWaM* is visualized in a Computer Augmented Reality display. 3D-graphics are layed over an image of a scene camera observing the prototypical scenario, see Figure 1.

With this Hardware-in-the-Loop environment key problems and behaviors related to autonomous visual guidance of a walking machine can be analyzed and studied. Specific motion effects of the vision system can be enabled and disabled when required. This approach facilitates an iterative development and implementation of the various algorithms involved.

The Hardware-in-the-Loop approach has accelerated the integration and the test of the developed visual guidance system on the walking machines *BARt-UH*, developed at the Institute of Automatic Control of the Universität Hannover (Prof. Dr. W. Gerth), and *Johnnie*, developed at the Institute of Applied Mechanics (AM) of the Technische Universität München (Prof. Dr. F. Pfeiffer). Several experiments with these robots proved the ability of the visual guidance system to lead the robots through prototypical test scenarios. During a typical experiment obstacles like barriers, ditches, boxes or stairs are overstepped, passed by or climbed. Corresponding innovative results are presented on the Hannover Messe 2003 to a broader public. Respective videos can be downloaded from `www.lsr.ei.tum.de/~vigwam`.

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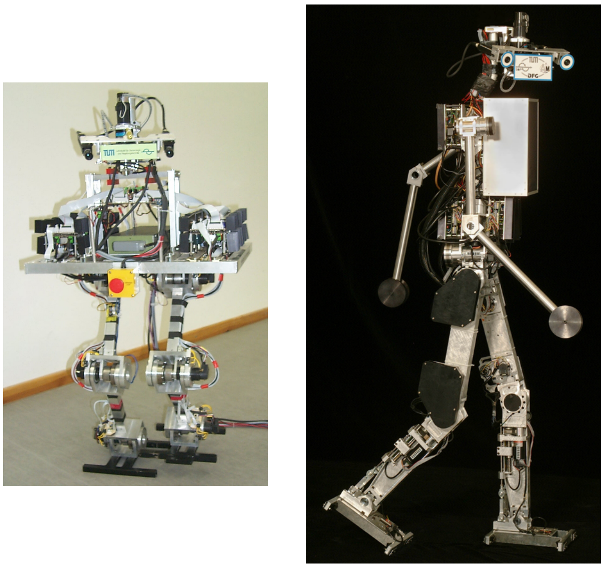

Figure 2: The biped robots *BARt-UH* (**left**) and *Johnnie* (**right**) together with our active stereo camera head – the key sensor of our visual guidance system.

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