An energy efficient gait for humanoid robots walking on even and uneven terrains

VALORIZATION

Traditionally robots are used for manufacturing tasks. Cars, for instance, are manufactured to a great extent by robots. The robots in car manufacturing repeat pre-programmed actions over and over again. More sophisticated robots are used, for instance, in container terminals to pick up containers and bring them to or from the ships. These robots do not execute the same sequence of actions over an over again, but adapt their action based on the goals set by the operators. Container terminals are a restricted environment and the autonomy of the robots is often restricted. Your self-driving car is a robot that has much more autonomy and must operate in an environment with much more uncertainty.

Robots have also appeared in our homes. We have robots that do the vacuum cleaning, mow the grass and entertain the kids. This is only the beginning. In the future, we will have robots that can do more complicated tasks, such as cleaning the toilets, washing and ironing your clothes, making order in the house, and playing football with your kids in the garden. These robots must be adapted to our living environment, which is designed for humans. It is therefore advantageous if the robots have a humanoid form. Such robots much have arms and hands to do tasks we humans are doing, and legs to maneuver in our environment.

A robot that has to maneuver in our environment must be able to walk on different surfaces, such as flat wooden or stone floors, (high) pile carpet, the grass in the garden, cobblestones street, etc. It must be able to step over obstacles such as children's toys on the floor, and it must be able to handle unexpected disturbances.

Besides being able to maneuver in our environment, a humanoid robot must also be energy efficient when walking in our environment. A humanoid robot has to carry its own power source and the capacity of modern batteries is still limited. Compared to the human walking gait, the walking gait of the humanoid robot is much less efficient. The difference in energy efficiency is partly caused by hardware differences such as using motors instead of muscles, but is also caused by differences in walking patterns. The former differences require developments in hardware while the latter differences can be addressed by developing intelligent controllers.

The research presented in this thesis contributes to both walking on different and possibly uneven surfaces, and to improving the efficiency of a walking gait. The results show that energy efficient walking gait of the humanoid Nao robot developed by Aldebaran can be improved by 41 % while walking on even grounds. Moreover, the energy efficient gait can also handle uneven terrains with bumps, holes and slopes. These results are not limited to the Nao robot. The proposed gait controller can be applied on any robot with a similar design, such as ASIMO developed by HONDA, the Wabian series developed by Waseda University, the HRP series built by Japanese National Institute of Advanced Industrial Science and Technology (AIST), HUBO2 from Korea Advanced Institute of Science and Technology (KAIST), Atlas developed by Boston Dynamic, the robot

H6 and H7 from University of Tokyo, Jonnie and Lola from the Technical University of Munich, and Sony's Qrio. What these robots have in common are the flat feet, which do not allow for toe-off, and full control over all degrees of freedom. Fine-tuning the gait parameters of the proposed gait controller for these specific robots using reinforcement learning, see Chapter 5.

The proposed gait controller uses under-actuated ankle joints. The walking gait should therefore also be applicable to robots with point feet, such as the RABBIT built as part of the French National Project ROBEA, MABEL developed at the University of Michigan, MARLO from Dynamic Legged Locomotion Lab at Oregon State University and HUME developed by UT Austin. For these robots the controller must be extended to handle the robot standing still since the absence of feet introduces a stability issue when the robot stops walking.

The approach developed in this thesis is applicable to the new development in humanoid robotics. The proposed approach identities an energy efficient gait for robots where the torque on the joints is the main source of energy consumption. The energy efficiency of a robot can be improved if actuators are developed and used in which the work done and not torque is the main source of energy consumption. The approach described in Chapter 4 to identify an energy efficient gait can also be applied when better actuators come available. The same holds for developments in hardware design. Walking with feet that can toe-off is considered to be more energy efficient. The WABIAN-2R from Waseda University and the Romeo from SoftBank (Aldebaran) are robots that have feet that can toe-off. With a small adaptation, the approach described in Chapter 4 can also identify the most energy efficient gait for these robots. The gaits identified may and probably will differ from the gait identified in this thesis. However, a controller can be developed in the same way as described in Chapter 5.

The whole approach outlined in this thesis may help people with walking disabilities in two different ways. First, we may build, physically or in a simulator, robots that can model certain walking disabilities. The approach described in the thesis can be used as a tool to investigate possible walking gaits given the disability. Second, the approach described in the thesis may be used in the development of exoskeleton for paralyzed people. Creating a stable gait that natural fits with the remaining abilities of the paralyzed person is an important issue.