ABSTRACT

Legged locomotion is effective in extreme ground conditions, but less effective with high speed on flat hard ground where wheeled locomotion is effective. We introduce a way to combine legged and wheeled locomotion (rolking) to gain effective mobility for mobile robot which has to operate in variable conditions including both natural terrain and structured environment. In addition to effective mobility, rolking mode enables possibility to measure the shapes and unevenness of the ground by probing it with the wheel-leg.

Keywords: hybrid locomotion, wheel-legged machine, control system, software architecture
1. INTRODUCTION

WorkPartner, illustrated in Fig. 1, is a futuristic service robot designed to be used mainly in urban outdoor environment. Mobility is based on a hybrid locomotion system, which combines benefits of both legged and wheeled locomotion to provide good terrain negotiating capability and large velocity range at the same time. Fig. 2 shows the mobile platform, called Hybtor, on which the manipulation and tooling system is built. The WorkPartner project and its mechatronic design have been reported in three previous CLAWAR conferences (1), (2), (3). The purpose of present paper is to continue the series by introducing development, which is done for its hybrid locomotion and motion control system.

![WorkPartner robot](image1)

**Figure 1 Design picture of the WorkPartner robot**

Similar locomotion system have been reported earlier e.g. by Hirose (4) and Zanthic Technologies Inc (5). These systems are not, however, so complete as to their controllable DOFs per leg as in this case. Either the wheels are not actively controllable like in Hirose machine or the legs have less than three DOFs like in Zanthic vehicle. The wheel-leg mechanism of WorkPartner has three controllable DOFs in the leg and one in the wheel.

![Hybtor platform](image2)

**Figure 2 Hybtor platform**
2. MECHANICAL AND SOFTWARE ARCHITECTURE STRUCTURE

2.1 Platform

The platform has an active body joint and four legs equipped with wheels. Each leg has three actively controlled joints and the wheel is also actively controlled. The weight is about 200 kg, including all mechanical components and the components of the energy system, the actuating system and the computing system. The payload is about 40 kg, which is mainly taken by the two-hand manipulator system. The actuation system is fully electrical and the power system a hybrid one with batteries and 3 kW combustion engine. The locomotion system allows motion by legs only, by legs and wheels powered at the same time or by wheels only. The robot can obtain 7 km/hour maximum speed when moving by wheels on a hard flat ground.

2.2 Manipulator

WorkPartner robot has a two-arm manipulator system illustrated in Fig. 3. It consists of a two degree of freedom body, two 3 degree of freedom arms and a two-degree of freedom camera head. The manipulator’s body is jointed to the platform with two joints, which allow orientation to horizontal and vertical directions. With the manipulator installed into the front of the body WorkPartner looks like a centaur, so instead of humanoid it may be called centaur.

![Figure 3 WorkPartner with the manipulator](image)

With two arms manipulator the robot is to be able to operate with large objects, the sizes of which exceed the arms grippers’ size. This is important in many service tasks. With two hands
the manipulator can handle objects up to 10 kg at 1 meter range. Motion of the manipulator and platform is coordinated by the overall motion control system.

2.3 General software architecture

The main software architecture of the robot is shown in Fig. 4. A systematic way to develop the software is considered very important in the project because of its large scale and number of people included. The robot will also evolve through several generations, which causes special needs to modular design and documentation of the software. Software planning and designing is done using UML description and the program code is written using object-oriented methods.

![Software architecture of the WorkPartner robot]

The software is divided into hierarchical levels, which communicate with each other using a special WorkPartner commanding language, which will be constructed by using the notations of the XML.

The operator can use the robot through two interfaces. The conventional interface, so called test interface, is built with a laptop and joystick. The advanced interface is a cognitive interface which utilizes different communication tasks on AI interpretation software. Working tasks are taken care by the manipulator system and transferring tasks by the navigation system. The Hybtor platform produces mobility services for the other tasks. Services of the Perception Systems are available throughout the architecture. A standard user interface can be used parallel to the AI level more advanced in future.
2.4 Software of the Hybtor platform

The software of the Hybtor platform is divided into separate parallel processes. Start/Watchdog activates all the other tasks in a predetermined order. Then it stays awake and guards the states of all the other tasks. Operations Interpreter acts as an interface between the platform and the upper hierarchy levels. Motion Controller takes care of all the calculations concerning the motion planning of the platform. Shared Memory contains all the measured data from the legs and the middle joint. Can Receive reads the measurements from the CAN-bus and writes them into the shared memory. Can Transmit sends all the controlling commands to the individual leg controllers or to the middle joint controller.

3. SIMULTANEOUS WHEEL AND LEG LOCOMOTION

The locomotion system allows motion by legs only, by legs and wheels powered at the same time or by wheels only. Hybrid locomotion means combining the wheeled and legged locomotion modes so that the propulsive force is generated by the wheel and the leg joints simultaneously. Hybrid locomotion could be called also ‘rolking’ (rolling-walking). A term close to this one (roller-walker) has been used previously by Hirose (4), but his rolking robot differs from WorkPartner in that its wheels are not powered. Rolking in this case resembles skiing, but instead of skis wheels are used (however, skis are not active devices like wheels in this case).

Rolking resembles a normal walking sequence. When a leg is in the supporting state the propulsive force is generated by distributing the moments between the leg joints and the wheel joint. How the distribution is done depends on the terrain properties and the speed of the platform. When the leg is in the transferring phase it is not lifted in the air, but unloaded and moved along the ground by touching it all the time and applying a slight forward moment to the wheel at the same time. All the joints of the leg, hip, thigh, knee and wheel are thus controlled actively all the time. Thus, for example, COG can be controlled during locomotion which is important when legs are moved. In the transferring phase it is possible to ‘feel’ the shapes of the ground and detect the obstacles by measuring the actuator currents and the joint angles (the leg is in a force control mode). The robot can then move on an uneven terrain by “probing” by the aid of feet. On a highly soft terrain (e.g. on sand or snow), where wheeled locomotion is difficult or impossible, it has been experimentally observed that rolking motion can improve mobility considerably.

Other benefits of the rolking mode compared to normal walking are better speed, stability and weight distribution of the platform. The leg can be moved to supporting phase instantly if needed, which improves the reaction responses. Speed is improved because there is no time wasted when lifting or lowering the leg in the walking cycle. Stability will not be easily lost and the weight distribution is more equally divided because the transferring leg supports itself when moving. Standard gait algorithms can be used. When the gait algorithm command a transferring leg to the supporting phase, it can be done instantly because the leg is already on the ground. This is very effective especially when free gait algorithms are used, which seems to be the natural choice in this case.

The main disadvantage of the rolking mode, if compared to the walking mode, is that the legs can be moved to the same direction as the wheels are rolling. The motion direction must be thus controlled like in the wheeled mode. In the case of Hybtor, steering is done by using the
articulated body. A minor disadvantage is due to the fact that legs are always contacting to the ground, which may cause problems in some applications (e.g. few foot places available on sensitive terrain). On the other hand, changing between the different locomotion modes is very simple and in fact they are all controlled by the same program using only different parameters.

4. EXPERIMENTS

4.1 Overrunning an obstacle by the aid rolking locomotion mode

In rolking, the transfer leg supports lightly the body and the wheel rotates actively by the velocity control. When the wheel hits the obstacle and is not able to go forward, the control algorithm starts to lighten the leg. Thigh and knee currents change according to the force reference. Wheel current changes according to the velocity reference. Overrunning an obstacle is based on simultaneous lightening of the leg and active rolling of the wheel. When the wheel is on the obstacle, lightening of the leg stops but the wheel continues rotation forward pulling the leg over the obstacle smoothly. Tests show that it is relative easy to find out a rough form of the obstacle, which we think can be utilised in several way in the future development of robot.

When overrunning of an obstacle, stability of the robot must be maintained. Center of gravity has to be transferred towards support legs. Climbing up stairs has been successfully demonstrated by the aid of the dynamic simulator of the robot. Climbing tests with the real robot are presently carried out.

One animation clip picture of Simulation test where the WorkPartner robot is climbing over an obstacle is shown in fig 5. The stepping leg is lightened and a force action of 85N is commanded to forwards direction. Driven wheel helps also climbing. Left front leg 1 is taking the first force controlled step over the obstacle and the other front leg 2 takes the second step. Between the first and the second step weight shifting is needed by changing supporting rear legs configuration and by using hip inclination. (6)

![Figure 5 Simulation test where the WorkPartner robot is climbing over an obstacle](image)

5. CONCLUSIONS

The rolking (rolling walking) locomotion mode seems to be a natural and effective way of moving for hybrid wheeled-legged machines. It combines the good features of both legs and
wheels in difficult terrain conditions. Terrain unevenness can be detected and relative big obstacles can be negotiated easily. In addition, stability of the machine is easily maintained because reflexive leg motion to support the body can be easily realized at any moment during the leg transfer state.

On a highly soft terrain, where wheeled locomotion is difficult or impossible, it has been experimentally observed that rolling motion can improve mobility considerably.

REFERENCES


