Further Development and Testing of the Hybrid Locomotion of WorkPartner Robot

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ABSTRACT
Legged locomotion is effective in extreme ground conditions, but not so good on hard ground with high speed. On the other hand, wheeled locomotion is excellent on hard ground with high speed but may be useless off-road when ground parameters change to be unsuitable for a wheel. In the previous conferences we have introduced a way to combine legged and wheeled locomotion to a hybrid mode, called rolking, to gain effective mobility both in natural terrain and in structured environment. In addition to effective mobility, rolking mode makes it possible to measure the shapes and unevenness of the ground by probing it with the wheel-leg limb during locomotion. The paper reports development and testing experiences of this hybrid locomotion. In the test, the WorkPartner robot is climbing stairs and rolking in a deep snow.

Keywords: hybrid locomotion, wheel-legged machine, control system

1 INTRODUCTION
WorkPartner, as 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. The WorkPartner project and its mechatronic design have been reported in four previous CLAWAR conferences (1), (2), (3), and (4). The purpose of present paper is to continue the series by introducing development, which is done for its hybrid locomotion and motion control system.

2 CONTROL OF HYBRID MOTION
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. A hybrid locomotion, which is called here as ‘rolking’ (rolling-walking), is a slow crawling locomotion mode intended to be used on an uneven soft terrain or to negotiate obstacles. Rolking
Fig. 1 The base position of the legs when moving. Probing the surface by using front legs can be done easily in this position. The rear legs are in important role, when the robot has to push upwards, e.g. when climbing stairs. The rear legs are nearer the centre of gravity, than the front legs, so they take care of bigger part of the mass than the front legs. This helps the front legs climb over obstacles and is useful during manipulations.

resembles skiing, but instead of skis wheels are used (however, note that skis are not active devices like wheels in this case).

Rolking works as follows: Consider 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. 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 (the leg is under force control) and applying a slight forward moment to the wheel at the same time. In the transferring phase, it is possible to ‘feel’ the shapes of the ground and detect the obstacles by measuring the joint angles.

2.1 Higher level control
In the rolking motion, the main functions of the overall control system are close to those of classical walking. Some new features are, however, needed. Gating algorithm, like wave gate or free gait, can be copied from classical walking.

In traditional walking algorithms, first the leg, which can be lifted to transfer phase, is chosen. In rolking mode, this part of the algorithm is alike. Next, the new supporting position where the leg is to be transferred is calculated according to the speed and direction of the machine and the form of the ground. This is also the same in rolking mode.

In walking algorithms, the next step is to plan transfer path, i.e., the height and shape of the path and the speed of the leg. This part differs the most. In rolking mode the shape and the height of the transfer path vary with the ground unevenness and can be measured online. The speed and supporting force are set beforehand and the lower level leg controller “lightens” actively the leg so that it moves easily along the ground.
2.2 Lower level control
In the rolking mode, the leg is controlled periodically during a working cycle, which is similar to the corresponding cycle in normal walking, including the supporting and transfer phases. In the supporting phase, the wheel is under position control and the leg joints make the propulsive stroke. The joint controllers are designed as combined moment and position controllers. In the transfer phase, all joints are controlled in a similar way but with different parameters. The wheel is controlled under speed control, which produces a speed to the direction of motion. In addition, the force by which the leg supports to the ground is calculated from the currents of the actuator motors. This force is controlled to a given setpoint, which is much less than the forces on the supporting legs but enough to keep the leg on ground during the transfer motion. If the leg collides with an obstacle or stability of the machine is lost, a logic reflex algorithm takes over and controls the setpoints of the basic controllers.

3. TYPICAL SITUATIONS TO USE ROLKING

3.1 Climbing stairs
WorkPartner can climb stairs in the rolking mode, as illustrated in fig 2. It is wise to climb up stairs in the rolking mode, because the wheeled mode does not work, and walking is more difficult to implement.

In rolking, the leg supports lightly the body and the wheel rotates actively by the velocity control. When the wheel hits the stair 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. Climbing on a stair is based on simultaneous lightening of the leg and active rolling of the wheel. When the wheel is on a stair, lightening of the leg stops and the wheel continues to rotate forward, thus pulling the leg forward.

WorkPartner needs for perception during climbing only position and current measuring of the joints. Forces, which are caused by the legs, can be calculated from the currents of the actuators.
The main problem in climbing is measuring the height of the stair. Height information is needed when the leg is changed to the supporting phase, after transfer phase. On the flat ground, the leg is set to a constant height, after the transfer phase has been completed. Climbing the stairs, the same method cannot be used. If the leg on the next stair is driven to the same height as the opposite leg, one stair below, the load between legs will be totally different (see fig 2). This would cause problems for the joints and the actuators. Therefore, the height of the leg on the next stair will be the height of the second leg minus the height of the stair. After both front (or rear) legs are on the same stair, the height will be changed back to the constant value.

The height of the stair is estimated by considering the positions of the legs. In fig 3, results for measuring the form of a stair are shown. Cartesian coordinates of the ankle point are measured constantly, while the leg is climbing on the obstacle. From the lowest graph titled as Form of the obstacle, the side profile of the stair can be observed. It must be taken into account that the ankle point is radius of the wheel away from the obstacle. This causes rounding of the corners.

Fig. 3 Cartesian coordinates of the ankle point, when the leg is climbing on the stair.
3.2 Climbing stairs downwards
The same rolling algorithm can be used when coming down the stairs. While coming down, the transfer leg moves forward under force control, and the wheel is under velocity control. The leg moves to the next stair, touching surface of the ground all the time. The leg will be switched to the supporting mode after coming down the stair. The same methods, as in the going up, are used.

3.3 Rolling on a highly soft terrain (sand or deep snow)
Rolling locomotion mode is useful in deep snow, as illustrated in fig 4. When the snow is deep enough, motion with wheels is not any more functional. By using rolling mode motion can be, however, continued. This same method works also in soft sand.

Softness of the surface can be measured in the rolling locomotion mode. The same idea was utilised with a traditional four-wheel ATV in (5).

Fig. 4 On the left WorkPartner is trying to drive in the wheeled mode into a deep snow, but the wheels are sliding. On the right it has changed locomotion to rolling mode and is proceeding. See video in: http://www.automation.hut.fi/IMSRI/workpartner/video.html

4 CONCLUSIONS
The rolling (rolling walking) locomotion mode seems to be a natural and an effective way of moving for hybrid wheeled-legged machines. It combines the good features of both legs and wheels when terrain conditions are challenging. Terrain unevenness can be detected and relatively big obstacles can be negotiated easily. In addition, the stability of the machine is better than in walking mode because the reflexive leg motion supporting the body can be realised at any moment during the leg transfer state.

One additional advantage of rolling must be mentioned. On a highly soft terrain (sand or deep snow), where wheeled locomotion is difficult or impossible to perform, it has been experimentally observed that rolling motion can improve the mobility considerably.
WorkPartner is designed for working with human. Using its hybrid locomotion mode, it can move in difficult unstructured environments as well in challenging structured environments, by using stairs when needed. This is very important feature for interactive service robot.

REFERENCES


