WORKPARTNER - FUTURE INTERACTIVE SERVICE ROBOT.

Halme A., Koskinen K.[+], Aarnio V-P.[+], Salmi S.*, Leppänen I.* and Ylönen S.**

Helsinki University of Technology, *Automation Technology Laboratory, [+]Information and Computer Systems in Automation, Espoo, Finland

WorkPartner is a new type of lightweight robotic working machine designed mainly for outdoor use. Mobility is based on a hybrid system, which combine benefits of both legged and wheeled locomotion to provide at the same time good terrain negotiating capability and large velocity range. It is called WorkPartner, because the goal is to make an adaptive and learning robot, which can carry different tools and work interactively with a human. The user or operator can be physically present on the same site as the robot and communicate with it by a wireless control unit, or he can use telepresence from a distance place and communicate via Internet. In each case communication takes place via a new generation user interface based on multimedia and cognition.

1. INTRODUCTION

Mobile working machine or service robot, which can work interactively with humans by using natural communication interface, is the challenge of next decade intelligent machines. In addition to the conventional applications of working machines, mechanization and automation of services of the society will increase demand of machines of this kind. The key properties then demanded are flexible mobility, ability to adapt to the environment and learning capability. All this, of course, in addition to execute the work tasks properly. Although such properties have been developed already to certain extent for robotic machines, most of the work is still ahead. An interesting launch for the development work of the new generation is P2 humanoid, published by Honda company in spring 1997, which is an excellent reference for development at the beginning of the new millennium. WorkPartner, shown in Figure 1, will be one of its challengers.

Figure 1. WorkPartner 1 robot. The chassis is already quite the final one but the manipulator system is under detail design and may still go trough changes.

WorkPartner, under development in Helsinki University of Technology and described in more detail below, is a new type of lightweight robotic working machine designed mainly for outdoor use. Mobility is based on a hybrid system, which combine benefits of both legged and wheeled locomotion to provide at the same time good terrain negotiating capability and large velocity range. It is called WorkPartner, because the idea is to make a highly adaptive robot, which can carry different tools and work interactively with humans by learning at the same time the details of the task. The user or operator can be physically present on the same site as the robot and communicate with it by a wireless control unit, or he can use telepresence from a distance place and communicate via Internet. In each case communication takes place via a new generation user interface based on multimedia and cognition.

2. PRESENT STATE OF THE RESEARCH AREA

WorkPartner will be a service robot, which works with humans. Several prognoses indicate service robots dominate the next phase in robotics industry. Presently they are studied widely all around the world. Service robots can work at home, in farms or in factories. The working environment can be outdoors like forests or parks, on water or under water and in space. Basically mobility is needed because the work tasks don't normally move, but the robot has to move to the tasks.

The service robots perform services, what kind, that is not necessary always known beforehand. Thus the robots may be designed for generic use in service sector, like the industrial robots today in industry. Because being very heterogeneous and fast changing the service robot area is not rewarding target for surveying. Instead, a couple of illustrative examples make more sense.

AGV service robots release humans from quite simple but time consuming transportation tasks. Transportation in this case can mean almost anything from pill-cans to humans.

INRIA and ROBOSOFT have developed a new generation of intelligent vehicles for Automatic Transport of people and self-service Cars. The vehicle, or robot, is called CyCap. It is two-seated, electrically driven mobile robot, which automation level can vary from basic controls to totally autonomous personal transportation system. (www.robosoft.fr)

Transitions Research Corporation (TRC) developed in the 80's a healthcare robot called Helpmate. It is a trackless, robotic courier system designed to perform material transport tasks throughout the hospital environment. Twenty-four hours a day, 365 days a-year, HelpMate transports pharmaceuticals, lab specimens, equipment and supplies, meals, medical records and radiology films through the hospital corridors. (www.pyxis.com)

The home environment will in the near future be the big area for developing service robots. The robots will invade the home both indoors and outdoors. Still there are not many robots for home use to buy, only couple of smart vacuum cleaners and lawn mowers.

One good example of home robots is Husqvarnas lawn mover called Auto Mower. (www.husqvarna.com)

Service robots, which can really do versatile services like a human, are still rare. Japanese company Honda has made a humanoid service robot, the newest version is called P3, which can do more than one type of services, but it is still in research and testing phase.

P3 is biped human like robot. With two hands P3 can do different kind of work and it is possible to program new tasks to do. Locomotion capability of P3 is good; Problem of the P3 is quite small operation time; batteries will empty in short time, in 15 minutes. http://www.honda.co.jp/english/technology/robot/index.html

3. WORKPARTNER

The Workpartner 1 is shown in Fig 1 above. The mobile platform, on which WorkPartner robot is built, is called HYBTOR (Hybrid Tractor) and shown in Fig. 2. It has four legs equipped with wheels and an active body joint. The weight is about 200 kg and the payload about 40 kg. The actuation system is fully electrical and the power system a hybrid one with batteries and a 3 kW combustion engine. The locomotion system allows motion with legs only, with legs and wheels powered at the same time or with wheels only. With wheels, the machine can obtain 7 km/hour speed on a hard ground. The purpose of the hybrid locomotion system is to provide a rough terrain capability and a wide speed range for the machine at the same time.

The platform will be equipped with a two-hand manipulator system as illustrated in the Fig 1. The manipulator will be a light weight construction (design weight about 30 kg) and can handle loads up to 10 kg. The mechanical design has been made in cooperation with Russian Rover Company LTD (St Petersburg) specialized on space robotics. In addition to technical design also art design is done. It will provide a stylish outlook for the robot by covering the body with panels. Industrial Design Institute at University of Lapland is responsible for the art design. The Automation Technology Laboratory at Helsinki University of Technology, which is the main contractor and coordinator of the WorkPartner-project, plans and implements the electronics and computer control system, the perception and navigation system and the user interface. The Information and Computer Systems in Automation Laboratory is responsible for the dynamic simulator used in testing the programs and developing control and operation methods.

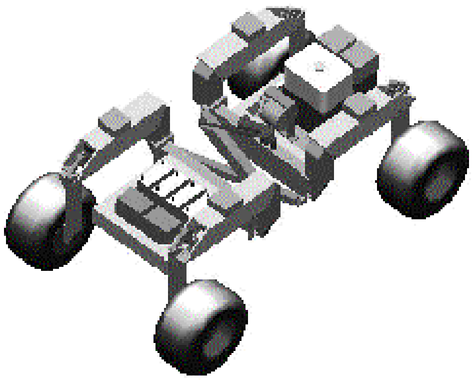

Figure 2. The platform 'Hybtor'

WorkPartner is a large-scale mechatronic research and development project, which also includes a large software development part. The leading idea in managing the R&D work is to make the design as modular as possible in mechanics, electronics and software. The WorkPartner project will continue several years after finishing the SMART-program. The project is public and can be followed on the Web-site:
www.automation.hut.fi/IMSRI/workpartner.

4. GOALS AND RESULTS OF THE WHOLE WORKPARTNER PROJECT

The WorkPartner-project is planned until the year 2005 when the third generation robot with all properties is ready. The schedule with the main subgoals is illustrated in Figure 3. The main goal of the project under the SMART-program is to get WorkPartner 1, the first generation prototype, ready at the end of March 2001.

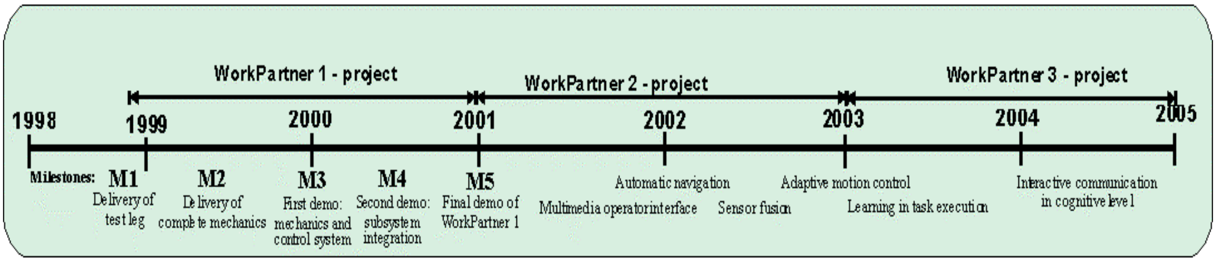

Figure 3. Time table of WorkPartner project.

The project is divided into eight work packages in each of which a certain area of needed technology is developed and applied at first to the WorkPartner 1 prototype robot. In the following the work done this far in the work packages as well as some of the main achievements are introduced.

4.1 Mechanical design and manufacturing

A key point of design is lightweight construction and electromechanical actuators. The mechanical parts are designed and manufactured by Rover Company LTD, St Petersburg, and Russia. The company has much experience on designing and constructing the planetary rovers in former Soviet Union space programs.

As the “muscles” the machine has identical linear actuators. Each of them consisting a Maxon EC250W 48V electric motor, a gear tailor-made by Rover LTD and a ball screw from SKF (CCBR32x100). Inside the rod of the ball screw a bolt’s axial tension measuring foil strain gage has been mounted. With the force sensor, forces can be detected also when the actuator is not actively powered. The linear actuators of WorkPartner have better force and velocity characteristic than commercial linear actuators available at the moment in markets.

The wheel has two functions, a rounded shape rubber wheel works as a foot in the walking mode and as a wheel in driving mode. The rubber wheel absorbs shocks generated in fast walking. With a gear reduction 84,2 the wheel reaches up angular velocity 462 °/s. This means that the vehicles maximum speed is approximately 7 km/h.

4.2 Design and implementation of the control system

The main function of the overall control system includes several new features if compared to classical walking machine functions. The hybrid locomotion system and automatic mode changes are features that have been studied only little so far.

The wheeled driving mode is like traditional wheeled vehicle, only additions are active balancing and attitude control and an active suspension. The walking mode is like any four-legged machines, only the foot is bigger than normally due the wheel. The hybrid locomotion mode could be understood as walking without lifting the legs, but unloading and driving them in the transfer phase. The control system should be able to change these modes automatically, also so that one leg could be in one mode and another leg in other mode.

The computer system is distributed around CAN-bus as illustrated in Figure 4. Each leg has one controller based on Siemens 167 Micro-controller and PHYTEC 167-mini-MODULE. A manipulator that will be added later is considered as an optional leg. Other nodes, demanding more computing resources - like those taking care of motion and locomotion control, user interface or perception system devices - are based mainly on PC-104 card technology. Also additional computer power can be used, via wireless local area network, WLAN. The main computer is a 586 PC-104 board and is running on QNX operating system. The electronics include also servo controllers for the actuator motors and specially made amplifier cards for force sensors in legs and shoulder actuators.

All the hardware is modular and easy to maintain. In a fault situation, the computer control system can be by-passed and the machine can be driven manually with an extra control box.

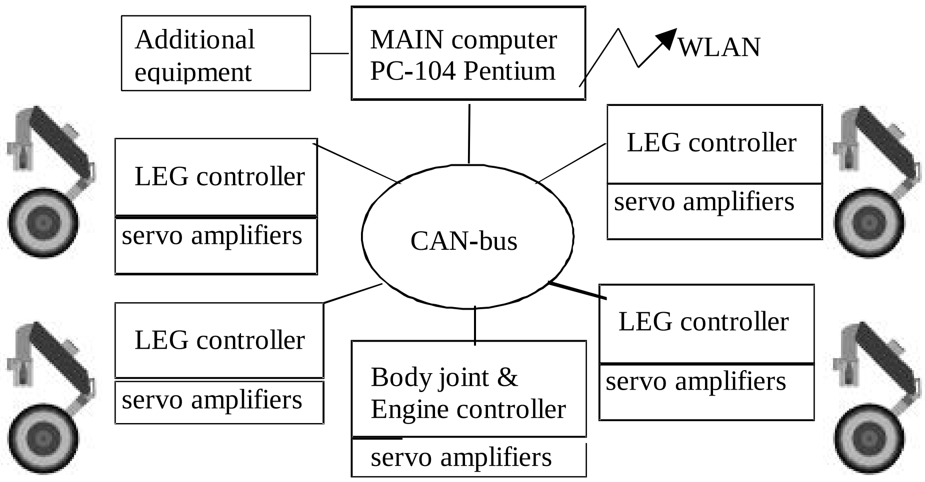

Figure 4. Overall schema of the on-board control system .

Architectural and detail designing of the software have been started and are done with the CASE-tool PROSA using UML description. A systematic way to develop the software is considered very important in the project because of its scale and number of people included. The robot will also evolve trough several generations, which causes special needs to modular design and documentation of the software.

The program code will be written with object-oriented methods and divided into logical parts and levels starting from the overall controlling part going down to basic controllers and limit switches.The main principle of the control software is presented in Fig 5. Because the machine can move in different modes, most of these objects have different modes, and sub-modes. This gives the code the basic modularity and also lots of challenges to make it functional.

The Operator Interface (*OI*) will in the first phase be more like a standard user interface, but in the later stages its role will be changed towards a high level multimedia interface through which the user can communicate with the robot like a working partner. Not shown in this basic diagram are the perception and manipulator modules, which will be joined later on.

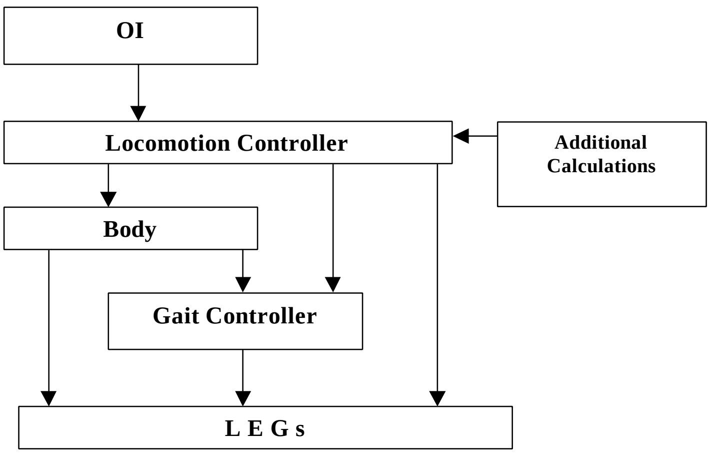

Figure 5. Principle of control software

The leg is controlled in different modes depending on the state of the robot and needs of controlling the body motion. The modes allow force, velocity and positional control of the joints. In addition, brakes in the motors are used actively to lock the joints when feasible. All these functions are taken care by the leg controller, which is commanded from the upper level of the overall control system. The design allows changes of control modes automatically so that the robot can change e.g. from velocity control to force control when stopping moving and starting working.

One of the control ideas is to ask service from each *LEG* and let the leg do most of the needed control algorithms by itself. Every leg is more or less individual object containing the whole leg including the wheel, all the controllers, sensors and limit switches, the control software, and the communication between leg controller and main computer. The legs cannot be totally independent agents because then they would have to communicate to each other and the only gait they could provide is simple wave gait. In our opinion there must be the overall control of the machine, in this case the main computer. In the *Walking mode* the leg is only asked to go to the next step position or to move the body to certain direction. The leg also can be forced to go to the support phase in the middle of the transfer phase. In the *Driving mode* the leg is either stiff or acts like a spring under the joint controllers and the service demands are routed to the wheel.

Gait controller controls the gating of machine according to the stability, walking mode and other needed info. It also controls the leg movements in hybrid locomotion mode.

Body object controls the attitude of the machine using the legs directly. In the driving mode it also calculates the body joint angle and the speeds of the wheels according to the operator commands.

The *Additional calculation* part contains many functions or objects, which gives vital information to the main part, locomotion controller. It includes, at least, Attitude Controller, Terrain Approximation, Center Of Gravity (COG) Calculation, Stability Calculations and Force Distribution Calculations.

Locomotion controller then gives orders, information or asks for service from all the other parts of the system. It chooses the right modes and commands the appropriate objects to gain the required movement.

4.3 Design and development of the hybrid power system

An idea of hybrid power system of the WorkPartner is to provide a big short-term power and to guarantee energy for long working and transportation tasks. Energy efficiency has also been taken into account. Therefore, a combination of the batteries and the combustion engine with a generator has been chosen, which is controlled by a microcontroller.

4.4 Development of the Man-Machine-Interface

User interface and the communication with humans will be an interactive concept, which utilizes commonly observed virtual world. The goal is to develop a user interface and control language way beyond the today’s interfaces and languages. The MMI will be designed for operators working outside the robot, but in some cases very closely co-operating with it. The robot can also be in a remote place and accessible via Internet. The MMI is designed to be multimedia based and highly interactive. It allows the operator and the robot to share a common virtual working environment and to communicate in a cognitive level with each other. Such an advanced level will be achieved, however, only in the later part of the WorkPartner program. During the SMART-program only a first prototype version of the MMI will be constructed which include the necessary elements to command the robot during task execution.

4.5 Navigation system

Navigation methods will be based on local co-ordination and natural feature beacons defined by the machine itself.

The navigation system computes the pose (position and attitude) of WorkPartner-robot relative to the objects found in the close working environment. It also maps the environment in such a way that tasks can be given to and executed by the robot. The basic navigation task is done by detecting features in the environment and using them as beacons. Camera and laser range finding scanner are used as the perception sensors. The robot also estimates change of its pose by using dead reckoning navigation based on odometer and a compass or gyro. GPS-receiver will be also used when the signal is available in outdoor environment. All available date is fused to get the best possible estimate for the current pose. The leading idea in designing the navigation system is that the robot adapts very soon and automatically, without the help of the operator, to the new environment where it has entered for working.

4.6 Basic sensing systems

Sensor fusion of a passive vision and active sensors of other wavelengths (ultrasonic, laser, and RF radar) will be developed to observe the local Environment.

The sensors of the body and the legs will be developed so that it is possible to recognize dynamic motions and detect shapes of the environment using the legs force sensors.

The WorkPartner needs to know its body inclination angles in order to maintain its stability at rough terrain. The body roll, pitch and heading angles are also used to estimate the shape of the ground under legs. The three angular degrees of freedom of the WorkPartner body will be measured by a modern compass equipped with an inclination sensor. The heading measurement accuracy is equal to 1,5 degrees. The measurement range of roll and pitch angles is from –50 degrees to +50 degrees and the accuracy is 0,4 degrees.

The perception of the environment is necessary in order to perform working tasks commanded by the operator. In the SMART 1 program the perception will be done by SICK LS291 laser scanner. It is able to detect obstacles up to 80 meters with directional accuracy equal to 0,25 degrees. The whole horizontal scanning range is up to 180 degrees. The vertical scan will be realized by installing this 0,45 kg device in the body of the manipulator system.

Stereo vision system with colour cameras will be used to support the recognition of different objects and in MMI to illustrate the environment model of the robot.

In the case the environmental map is reused again after forming it in the first time, it must be linked to the global map. This planned to be done in outdoor environment by a cheap GPS receiver. The Selective Availability disturbance is not active after 1st of May 2000 and the standard deviation of the position error is decreased to 3 meters. The accuracy of GPS speed measurement is equal to 0,1 m/s. The position and velocity of the WorkPartner will be available on every second.

4.7 Industrial designing

From the beginning of the project also the art design, the appearance of the robot, has been taken into account. The Department of Industrial Design, from University of Lapland, has taken part to the project from its early days. Though the robot is a prototype and first of its kind it should not look like one.

4.7 Manipulator

In order to do work WorkPartner robot will have a two-arm manipulator system. When writing this document the detail design of the manipulator system has not yet been completed.

However, according to the architectural it will consist of a two degree of freedom body, two 5 degree of freedom arms with a gripper and a two-degree of freedom camera head. It will look like a human upper body, shown in the Fig 1 above. The manipulator's body is jointed to the platform with two joints, which allow orientating of it in horizontal and vertical directions. With the manipulator installed into the front of the WorkPartner's body WorkPartner look like a centaur, so instead of humanoid it can be called centurion robot.

Working tasks require an advanced control system, especially as to force control, therefore the manipulator has a separate control system which is connected via CAN bus to the main control system of the robot. Working tasks are performed with a help of camera information autonomously or interactively with the operator.

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. The manipulator can handle objects up to 10 kg at 1 meter range. The gripper can be replaced with working tool, like cutting tool.

5. CONCLUSIONS

WorkPartner is a very ambitious research and development project, which includes mechanical, mechatronical and software components. It is and a good example of a "smart machine " of the future. WorkPartner robot integrates in one system almost all the themes and aspects, which have been dealt with under the SMART, program. When the project closes in April 2001 the robot will not be finally ready. However, the project will produce the first prototype, which is able to demonstrate some ideas of all the features intended to the final robot. It provides an excellent platform for further development of next two prototype versions with more advanced features. Most of those features will be realized by the aid of software and by adding more sensors to the system. The basic mechatronics, which was designed and built during the SMART program, will not change much.

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