The Future Worksite Demonstrator: a hardware infrastructure for testing automated earthmoving for planetary applications. E. Halbach, T. Ylikorpi, J. Suomela, J. Saarinen and A. Halme, Aalto University Department of Automation and Systems Technology, P.O. Box 15500, 00076 Aalto, Finland. eric.halbach@aalto.fi

Introduction: Earthmoving capabilities will be necessary for establishing a human presence on the Moon or Mars. Tasks foreseen include bulldozing and excavation for base construction, burying pressurized cabins inside regolith for radiation shielding, and obtaining regolith to harvest water, oxygen and other elements for in-situ resource utilization. The use of remotely controlled robotic earthmoving machinery will increase the safety of human operators in these hazardous environments. Various control schemes for such scenarios are possible, depending on the physical location of the operators. If located on site, tele-operation or even direct interaction would be possible; however, if located far away (in orbit, or on Earth), time-delays would necessitate a high degree of machine autonomy. Even if located on site, a high amount of machine autonomy would be desirable for reducing operator workload and increasing productivity.

In an advanced tele-operation scenario, one operator would be able to control multiple machines equipped with necessary autonomous capabilities. The concept of tele-presence gets a new meaning: the operator no longer concentrates on operating a single machine, but instead needs an overview of the whole situation (situational awareness). This would combine the perception capabilities and intelligence of a human being with the power and strength of machinery.

A mixed control scenario involves the combination of remote control and proximal interaction. Proximal interaction requires humans and robots to be operating in the same space, where the interaction can still take many forms, e.g. local tele-operation or natural communication between a human and a robot, see Fig. 1. In recent trends humans are no longer only operating the machines, but rather working with them. [1] [2] [3]

This paper introduces the Future Worksite Demonstrator (FWD), an existing hardware infrastructure developed for field robotics research at the Finnish Center of excellence in Generic Intelligent Machines (GIM). The paper also presents 3D graphical techniques for job-level control of semi-autonomous earthmoving tasks.

Future Worksite Demonstrator: The FWD is a distributed multi-entity system where at the worksite level there are one or more machines and humans performing the actual work. The work is supervised remotely by one or more operators; currently the control of the worksite is possible through the Internet from anywhere in the world. [2] [3]

Figure 1. Human-robot proximal interaction.

The FWD, as the name suggests, represents a “worksite of the future,” which is an unstructured outdoor environment with necessary support (wireless communication, external sensors) and the entities (machines and human workers) within. Tasks being performed include transport, earthmoving, ditch digging and bulldozing. The FWD includes an outdoor test field and a covered 20x20m test hall with a sand ground, both located in Tampere, Finland.

The machinery consists of two skid steered and one articulated frame controlled compact wheel loader from Avant Tecno. These commercial off-the-shelf products are modified to be computer controlled with sufficient sensing capability. The machines have a two-level control system consisting of an embedded CPU and on-board PC computer connected via CAN bus. Connection to the Internet takes place through WLAN. The sensor system includes a stereo vision unit, 2D laser scanners for localization and obstacle detection, plus necessary sensors for closed loop control of hydraulic actuators. In addition to the real machines, simulated loaders can be added for multi-machine scenario testing, as in Figure 2.

Figure 2. The Future Worksite Demonstrator with real and simulated machinery.

The communication data travels through the Internet both ways and the robots are controlled in real time from the remote control station. [3] [4]

Worksite modeling: In all human–robot interaction the common understanding of the environment is a key issue in the communication. The base of the common model is the geometrical environment model common for all entities. The worksite state is recovered by using a 3D laser scanner. This base model represents the initial state of the worksite and it is updated when the state changes. The model is further post-processed into a ground model (height map) for trajectory planning, occupancy grid for localization and polygon model for visualization. Field robots by definition change the state of the worksite while working, therefore the model should be updated constantly. [1] [3]

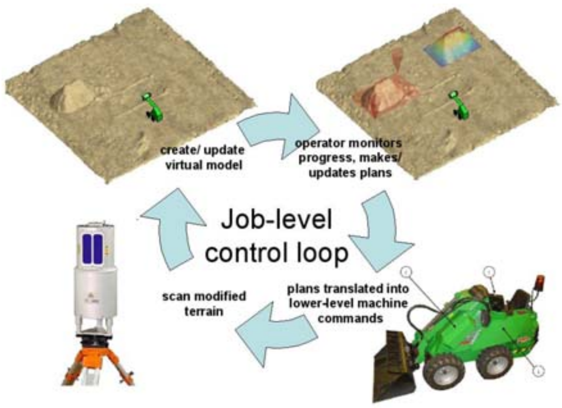

Figure 3. Job-level control of earthmoving tasks.

Human supervision using 3D graphical tools: Humans still have a big role to play in the Future Worksite. They are the experts that explain tasks to the autonomous machines. To enable a human operator to control one or more earthmoving robots in a mainly supervisory role requires the establishment of a job-level control loop (see Figure 3.) The loop is initialized using the common model of the worksite. The operator then makes a high-level work plan, for example specifying a pile to remove or area to excavate, using interactive 3D graphical tools rendered onto the common model. This plan is translated automatically into lower-level commands for one or more remote work machines to follow. The loop is closed by sensing the changes by the laser scanner. The virtual model is updated, and the cycle repeats. The operator nominally just monitors as work proceeds, but can intervene if necessary to update the plan or take more direct control of the machines.

This strategy was tested for a bulldozing job, first in a simulator and then by performing an outdoor hardware experiment. In the simulation (Figure 4), a rectangular area and clearing direction was first specified by the operator, after which the machine automatically cleared it from right to left. An outdoor bulldozing test was then performed by manually driving an Avant wheel loader and using snow as the ground material (Figure 4), with laser scans being made after each clearing drive (Figure 5). Afterwards, the same graphical job planning tools were applied with the real worksite data (Figure 5), and it was found that they were able to detect changes in the workspace and determine where the next clearing drive should take place. [1] [3]

Figure 4. Bulldozing simulation with 3D graphical job planning tools (left). Outdoor test (right)

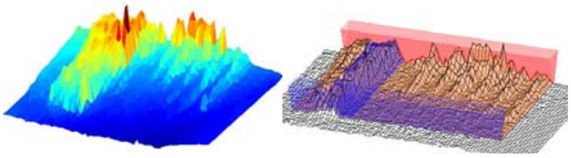

Figure 5. Laser scan from outdoor test (left) applied with 3D job planning tools .

Conclusions: The ability to remotely control robotic earthmoving machines without the need for direct tele-operation will be very beneficial for constructing bases on the Moon and Mars. The Future Worksite Demonstrator (FWD), with several remotely operated earthmoving machines, has been built for developing these capabilities. 3D graphical tools have also been developed for the supervisory control of these machines. Autonomous bulldozing was tested in a simulator, while real surface scans were then integrated with the same graphical job planning tools used in the simulator to track progress and determine subsequent actions. Development work continues with a goal for increased autonomy and efficient task planning and execution.

References: [1] Halbach E. and Halme A. (2010) *IAC-10.B3.6.-A5.3.2.* [2] Saarinen J. et al. (2007) *Proc. 13th IASTED International Conference on Robotics and Applications Telematics.* [3] Saarinen J. et al. (2010) *GIM Internal Report.* [4] Saarinen J. et al. (2007) *Proc. 10th International Conference on Fluid Power 2007.*