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A Tele-Autonomous Heavy Duty Robotic Lawn Mower

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Abstract

This paper describes the development of a robotic heavy duty lawn mower provided with a rich set of sensors which initially provide tele-operation mode capabilities but will support extension towards full autonomy via an intermediate mode termed tele-autonomous to reflect a multilevel control structure which permits graceful withdrawal of human guidance as the development proceeds.

1. Introduction

Outside the confines of well structured factory settings robotic automation can only be approached by the provision of richer sensors and higher levels of artificial intelligence. The less structured and time-varying the environment the more challenging the task. However, there are practical situations where some degree of human intervention is acceptable. These include circumstances where the main purpose is not the reduction of human labour, but the removal of humans from dangerous and/or uncomfortable work sites such as in underground mining, subsea operations and in space exploration. Also within this class is the case of providing a disabled person some degree of protection from collision whilst permitting that person maximum freedom to control a wheelchair within such an envelope of safety. In this case it is both psychologically and physically sound to provide minimal intervention so the disabled person s motor skills and confidence are not undermined [Jarvis, 2001].

Sensor rich teleoperation (or telepresence) can often provide an adequate solution where remote operation of equipment in hazardous situations is all that is needed [Jarvis, 1999]. However, some degree of automation is usually an advantage in reducing the stress of the operator by reducing the potential for collision.

One consistent approach to providing some degree of autonomous behaviour between pure teleoperation and full autonomy is to consider what is required for the latter in terms of sensors, control and intelligence and then to withdraw from this extreme position to a point which is comfortably within a reliability zone for the task at hand, with human judgment bridging the operational gap which currently can not be spanned by existing technology and know how at an acceptable price and reliability.

This approach not only has the advantage of providing here and now solutions but points to a tractable path towards full automation in the fullness of time as sensor technology and artificial intelligence methodology mature to meet the challenge.

This paper concerns one such development involving a heavy duty mowing machine [See Figure 1], richly instrumented with sensors and computational support which can now provide a hybrid capability between pure teleoperation and full automation, termed tele-autonomous by the author. The intention is to move towards graceful withdrawal of the human element when top-level planning strategies are perfected, thus rendering the system fully autonomous.

Figure 1(a). Stiga Pro. 20 Mower — Fully Instrumented

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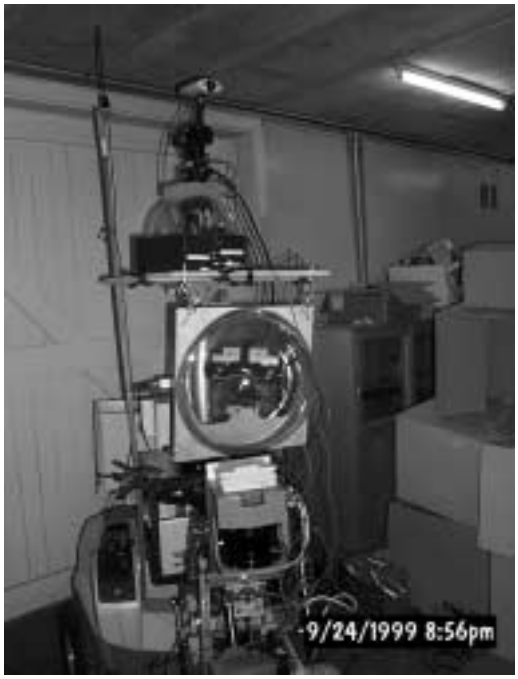

Figure 1(b). Stiga Pro. 20 Mower — Close Up of Sensors

The next section details the instrumentation of the mower. Then follows a description of the control strategy used to drive the mower. Next, some preliminary outcomes are presented, mainly concerning functional components not yet fully integrated. Finally, a concluding section provides a discussion on the project and of future work.

2. Instrumentation

Figure 2 shows the rich set of sensors and computational support provided for the Stiga heavy duty lawn mower used for this project. The mower itself was selected with great care to maximise its suitability for being automated and its maneuvering ability on rough ground. The Stiga Pro. 20 chosen, is powered by a reliable four stroke petrol engine but has a hydrostatic drive system which allows for very smooth movement (no gear changes) with the engine running at fixed rpm. The unit is also provided with power steering and cruise control. The machine has an articulated body with the steering provided by changing the angle between the front and the rear halves. The rear half houses the petrol engine and the front half carries the mower attachment and, ordinarily, the driver. The mid body articulation joint permits some movement around the longitudinal horizontal axis, making for improved four wheel ground contact in bumpy terrain.

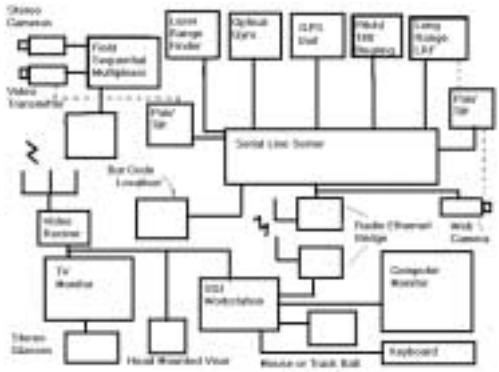

Figure 2. Instrumentation Schematic for Stiga Pro. 20 Mower

The following instrumentation is provided:

1. Erwin Sick scanning laser rangefinder (up to 50 metres).
2. Phase Mode/Differential Global Positioning System (GPS).
3. Optical Gyroscope (with axis vertical).
4. Stereo Video Camera pair.
5. Web Camera (with its own IP address).
6. Long Range Laser Rangefinder (up to 400 metres).
7. Denning Bar Code Reading Localiser (up to 30 metres).

Not all the above sensors are needed simultaneously for the mowing tasks being considered. However, since the mower is being used as a sort of flag ship for other on-going projects, this rich set of sensors provides a basis for a variety of experiments to determine adequate sensor combinations for different kinds of task as well.

The stereo video cameras are used in field sequential mode with a single left/right multiplexed signal being transmitted by a video transmitter to the home station video monitor; a three antenna diversity video receiver system is used to provide quality video from the moving vehicle. A 3D view can be obtained either using switching glasses and the monitor or via a demultiplexing head mounted visor (which also permits look through to other screens). The camera pair can be replaced by (or enhanced by) a Triclops stereo ranging system for fuller automation at a later stage of development.

Two pan/tilt systems are provided, one for the stereo camera pair and the other to steer the long-range laser rangefinder. The long-range scanner s functions for this and other related projects are still being considered. Whilst a large scale range scan of a working environment is possible, the time involved to gather the data as a detailed range panorama would be quite long (perhaps many minutes). This may be acceptable if done infrequently to build large-scale environmental maps.

An alternative use could be as a target tracking localiser system. A telescope/video camera mounted more-or-less coaxially within the range scanner beam could be used to direct the scanner at suitably contrived and positioned targets, the distances to which could be used to triangulate the vehicle s position as well as determine its orientation.

Only two such targets need be tracked at any one time; however target obscurance may need to be accommodated by using more, yet distinct, targets. Tracking reduces the need for any but a very local search for the targets once they have been acquired. Setting up simple visual targets would clearly be acceptable for mining or agricultural automation applications but not, for example, for search and rescue in unknown (particularly rough) terrain.

A web camera is mounted (with its own web address) with the long-range laser scanner. It can return images to any computer on the web.

The optical gyroscope can be used for steering control since it can indicate a change of direction accurately but accumulates absolute bearing angle errors over time.

The GPS system combines differential mode (no longer as critical as it once used to be before the termination of the so called selective availability deliberate clock error by the United States defence forces) with phase mode to return a fix to an accuracy of 20 cms.

The Denning localiser functions by laser scanning large bar code targets closer than 30 metres from the unit. The location/orientation fixes it provides are accurate to 3cm and are made available at a 10HZ rate. Obviously, a 30 metre range is of no real use for continuous localisation over large areas. However, it would be possible to use well-placed targets to occasionally correct for localisation errors accumulated by, say, odometric methods. Odometry was used on a previous outdoor navigation project [Jarvis, 1997] and could be included in this project if deemed useful at later stage.

A pitch/tilt/bearing (flux gate) sensor can provide information about the pose of the vehicle (or a particular sensor if preferred) on rough and/or sloping ground as well as bearing. This could come in useful for environmental mapping and/or to limit the pose of the vehicle to safe attitudes on hillsides.

It is clear (as indicated earlier) that this set of sensors provides more than what is needed for this particular project. They have been installed for studying a variety of navigation styles, some more suitable for particular applications than others.

A four km range 11mbit radio ethernet bridge system links the on board sensors to a home base. Steering and speed (and ignition cut-out) control is provided via a microprocessor controlled digital potentiometers which substitute for joy sticks on a standard (old fashioned) radio control transmitter which itself controls up to four servo motors. The transmitter can be taken off the vehicle for direct (manual) remote control during experimental set up stages of the project. A simple switch flips between manual and computer control. This flexibility makes the testing and adjusting of various aspects of control quite easy. Three servo motors are used to control steering, speed and ignition safety cut-out, respectively. Speed is controlled by adjusting a single pedal using a gate opener lead screw linked to one servo. Forward and reverse are controlled by the same pedal. Steering is effected utilising a bang-bang control system using the position of a second servo as the input. The fact that steering is hydraulically assisted makes the motor torque requirement quite manageable despite the weight of the vehicle and its body articulated steering mode. The third servo is spring loaded to cut ignition by control or when the radio link fails. The vehicle has a very small turning circle since the front of the vehicle can swivel on the articulation joint up to – 80 degrees.

The long-range laser rangefinder, the Erwin Sick scanning rangefinder, the bar code localiser system, the GPS system, pan/tilt/bearing sensor and the optical gyroscope all have their own graphical output displayed on the screen of the home workstation; the web camera image is also viewed on the workstation screen.

3. Tri-level Control Strategy

Whilst many robotics systems covered in the recent literature are based on either low level (reaction mode) control or high level (planning) control, a third, intermediate level combined with the other two (rather than competing with them) can provide very effective control. In this paper, the author recommends such an approach as one which simultaneously provides safety, reliability, flexibility and efficiency.

In this paper the three levels of control are referred to as Reactive (low level), Anticipatory (middle level) and Planning (top level). When this project moves from tele-autonomous mode to fully autonomous mode only the top level need be modified by replacing human perception and judgement by artificial intelligence reasoning about sensor data.

The idea of this tri-level control strategy arose from a related project that was concerned with minimal intervention wheelchair control which adapted to the user s navigation skill level on an individual basis [Jarvis, 2001]. In this case, the user provides top level (planning) control but the anticipatory and reaction levels are fully automated. That the user is on-board a wheelchair and not controlling a lawn mower at a distance is not crucial to the conceptual framework if rich sensory data is transmitted to the operator in the latter case.

In the wheelchair case the reaction level provides a gradual slowing to a stop on imminent forward collision detection and a veering away from obstacles on the left or right side if too closely approached.

The Anticipatory level is provided in the following way:

1. Sick scanning rangefinder data (over 180^0 forward horizontal planar scan) is plotted into a 32 x 32 grid representing a six metre by six metre square in front of the vehicle, which is considered to occupy a middle tile at the bottom of the square (exact position not critical). The bottom line of the grid structure is filled in to force analysis to consider only forward movements.
2. The cells immediately surrounding obstacle cells are filled in to partially compensate for the footprint of the vehicle (a two cells layer may be better).
3. A Distance Transform (DT) [Jarvis, 1994] is carried out away from the obstacles, filling all of free space with values indicating the number of steps to the nearest

obstacle. The obstacle cells are each themselves set to zero.

4. From the cell representing the vehicle, scan, from the 30^0 direction to the 150^0 direction at 2^0 intervals with a series of radial trajectories out from the vehicle cell up to a maximum of six metres. For each radial scan accumulate the DT values of cells penetrated until either a zero is found (obstacle encountered) or 6 metres have been traversed.
5. The direction that is associated with the highest accumulation of DT values is considered the safest direction to go, in a fairly localised sense. This is called the recommended direction and is clearly of an anticipatory nature, going beyond imminent collision avoidance. An example result is shown in Figure 3.

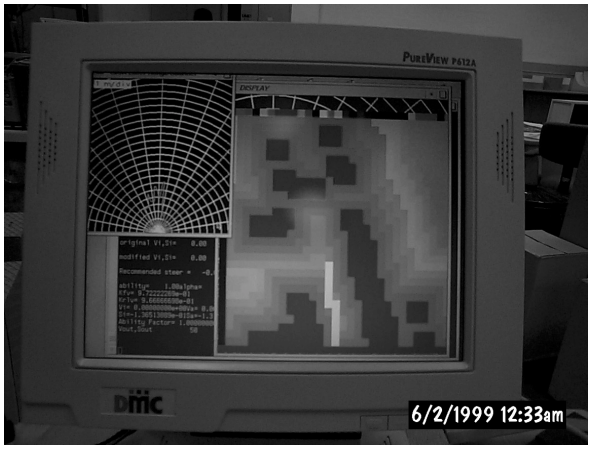

Figure 3. A Recommend Steering Angle Result

The system is not privy to the high level planning strategy of the user but the user s (operator s) intention is indicated by a mouse controlled cursor position on the screen, with speed along the vertical axis and steering along the horizontal axis. A square region in the centre of the screen represents a dead zone where there is a dead stop (no speed, no steering control). The user can retreat to this zone at any time. Whilst intended speed is modulated by imminent collision analysis and user ability measures (based on recent prior history of having come too close to obstacles), steering direction is determined by linearly mixing the operator s steering intention with the range sensor derived recommended direction in proportion to the operator s ability. That is, a perfectly able operator would not have his/her steering intention modified at all and a perfectly wretched operator would be totally overruled in favour of the recommended direction; all mixes in between are also possible. In fact, the outcome of this mixing is further subject to the veering away low level adjustment to avoid side obstacles.

In this way all these levels operate together. Experiments indicate that the strategy is quite reliable and smooth (not erratic). The whole tri-level control strategy is illustrated in Figure 4.

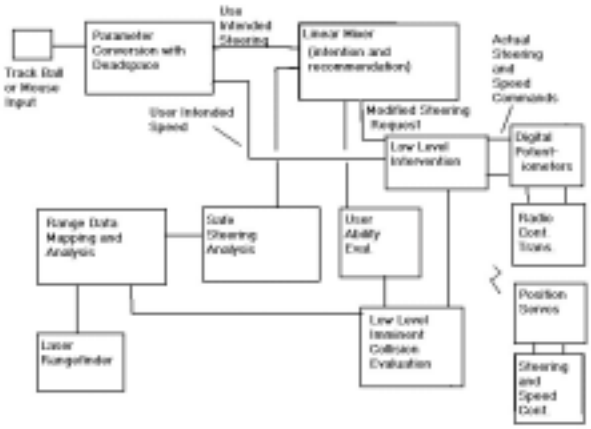

Figure 4. Tri-Level Control Strategy

The whole of the above strategy is being transferred from the wheelchair project to the lawn mower project.

The mowing operation is carried out as follows:

a. The operator powers on all instruments and starts the mower.
b. The position of the mouse cursor indicates the intended steering and speed except for a dead space square in the middle of the screen.
c. The following graphic information is available on the workstation screen:
   I. Erwin Sick Rangefinder scan data plotted as a set of distances linked by a line over a 180^0 degree sweep, but only a 90 of a possible 360 readings are used (to improve reaction times).
   II. A needle indicating pitch, roll and bearing in 3D.
   III. GPS derived position tracked in a window on screen.
   IV. Web camera view in a window on screen.
   V. Switched glasses or head mounted visor 3D view collected by the on-board stereo cameras.
   VI. A dial in a window on the screen showing the long-range time-of-flight rangefinder value (full dial covers 0 to 409.6 metres).
   VII. Optical gyroscope dial in a window on screen.
   VIII. The Erwin Sick scan data plotted, on a 32 x 32 grid with the recommended steering direction indicated.
d. The operator uses whatever sensor information is required to manoeuvre the lawn mower around a large environment without needing to see the mower. The radio ethernet bridge can operate up to a range of 4 km (line-of-sight).
e. The middle level (anticipatory) and low level (reaction) modes operate continuously to avoid imminent collision and to anticipate near potential of collision, influencing the vehicle to move to safer areas in the latter case.

All that is required to move from this to tel-autonomous mode to a fully autonomous mode is to substitute the operator supplied mouse cursor position using some high level path planning strategy [Jarvis, 1994, Chatila and Lacroix, 1996]. This top level strategy need not be particularly precise as the lower levels of control should look after very localised risks. In relatively open field

situations the mower operation should be smooth, safe and reliable.

4. State of Play

All of the sensors described in the previous section except for the optical gyroscope (which is currently being used on another project but can be transferred easily to this one) are installed on the mower. Also, the reaction and anticipatory control processes have functioned correctly on the wheelchair project and can also be used on this one except for the link between the steering/speed commands and the serial line driven microcontroller which provides digital potentiometer values to the radio transmitter, which in turn adjusts the steering and speed servoes. This part of the preparation is not difficult but has yet to be completed.

It is anticipated that the whole system would be fully operational within two months so that video sequences demonstrating the working mower should be available for presentation at the ARAA conference.

Future work includes the careful study of which of the many on-board sensors should be used for the mowing project to make the system fully autonomous by the replacement of the operator by a top level planning strategy. Previous experience with path planning algorithms [Lozano-Perez and Wesley, 1979; Brookes, 1986; Latombe, 1991] should allow this development to proceed smoothly.

5. Conclusions

A tri-level control strategy for a heavy duty mowing machine has been described. The two lower levels of control (reaction and anticipatory) provide local support for obstacle collision avoidance at both an imminent and local level, with the top level planning being provided by the operator. It is intended to render the whole system autonomous by replacing the operator with a high level path planner which uses accumulated environmental mapping data as its basis of reasoning about how to best fulfil the mowing task at hand.

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