SENSOR RICH TELEOPERATION OF A TRACKED, HEAVY DUTY VEHICLE IN OUTDOOR ROUGH TERRAIN

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Abstract

This paper takes the unusual stance of stepping back from the full automation of a heavy duty robot vehicle, capable of operating in outdoor rough terrain environments, to consider teleoperation within the context of sensor rich data presented unambiguously to the operator at a safe, stationary workstation site. Whilst complete sensory immersion is not attempted, the quality and overlapping modes of the sensory data and its presentation permit smooth and accurate control of the vehicle in an open field rough terrain environment which may contain a variety of complex obstacles, possibly densely distributed. Applications in fire fighting and landmine clearing come to mind as excellent ways of exploiting the capabilities of this system.

1. Introduction

The usual aim of Intelligent Robotics research is to apply sensor technologies and Artificial Intelligence methodologies to the automation of useful behaviour in a physical machine. The extent to which complex tasks can be automated without human intervention and the extent to which operations can be generalised over tasks and environments are the usual measures of success.

However, in this paper, a step back from automation with a human clearly in charge but using all the sensors and controls ordinarily used for automation is promoted as a feasible and safer alternative which could have practical application potential over a number of domains. The quality of this teleoperation mode of control depends on two factors, the richness of the sensory data collected to describe the state of the machine in its working environment, and the effectiveness of the visualisation aids which empower the human operator in the process of controlling the machine. These aids allow the human operator to fully appreciate the situational reality of the machine and provide the means by which the operator can modify it with flexibility and reliability in support of the task at hand.

What follows is a case study of a teleoperation exercise involving a heavy duty tracked robotic vehicle in outdoor situations which could involve rough terrain navigation. The next section will deal with the sub-system requirements for autonomous operation but with the teleoperation mode requirements introduced as alternatives when relevant. The particular robot vehicle system will then be described in detail along with the sensors and visualisation/control aids. Next some preliminary trials will be described. Finally a discussion section with a conclusion will be presented.

Whilst this paper is not about virtual reality it comes close to a halfway point between mere teleoperation and what is often called tele-existence which tries to create the sensation of the operator actually driving the machine on site. The effect is not immersion but is, in some ways, better since it allows a more complete appreciation of the machine at work than could be obtained under normal on-board driving conditions, especially in open field environments.

2. Mobile Robot Navigation

Six sub-system requirements unambiguously define robot navigation [1,2]. Firstly, the position and orientation of the vehicle should be known (localisation). Secondly, the position and extent of obstacles in the environment should either be known or be capable of being sensed during the navigation process. Thirdly, acceptable (or even optimal) collision free paths to nominated goal points should be calculated or judged. There are many path planning methodologies [3,4,5], which are available here, but in teleoperation mode, the operator can make his/her own decisions, perhaps after taking advice from a path planner. Fourthly, a motion control system which directs the vehicle along the chosen path is needed for whatever mode of locomotion is being used (wheels, tracks, legs, paddles etc.). Fifthly, there is a need for the various subsystems to communicate with one another and for on-board systems to communicate with a base station if such exists. Finally there is the question of defining the task itself, whether to go to a particular location, find specified objects, explore regions or cover all free space such as in a cleaning or mowing/harvesting operation.

For autonomous mobile robot navigation there is a need for tightly coupling sensor, control and reasoning aspects of the task.For teleoperation the same three

components are tightly coupled but a human is providing much of the reasoning component, even though some advice may be provided by computational processes.

3. Mobile Robot Vehicle and Navigation System

A Modulaire MD15 heavy duty tracked vehicle was used for this study [See Figure 1]. It weighs 1200 kg and can haul 2000 kg. Its diesel engine provides hydraulic fluid pressure to swash-plate motors which drive the two tracks independently. Hydraulic valves control the speed of travel and these in turn are electrically controlled. Steering is obtained by differential track speeds; opposite and equal velocity track movements turn the vehicle on the spot. The vehicle can move up to approximately 12 km/hour. Such a vehicle is fully capable of hauling farm implements, mowing attachments, water tanks (say for fire fighting) or armoured machinery for land mine detonation. Since fire fighting and land mine detonation are activities which are intrinsically hazardous, these are excellent candidates for teleoperation where using humans in the loop, but at a safe distance, is certainly acceptable.

Figure 1
Modulaire MD15 Heavy Duty Tracked Mobile Robot.

Localisation can be supported using four different sensor modes each with its own special flavour. The primary mode is differential/phase mode Global Positioning System (G.P.S.). Our equipment is capable of positioning accuracy of 20 cm root mean squared (r.m.s.). Supporting this mode, a video camera can be hauled up the same tower [See Figure 2] used for the stationary G.P.S. receiver and can be controlled for pan, tilt and zoom from the ground It is difficult to judge rotation accurately using either of these. Both odometry wheels [See Figure 3] and an optical gyroscope can be used to measure turn angles quite accurately (± 1 degree).

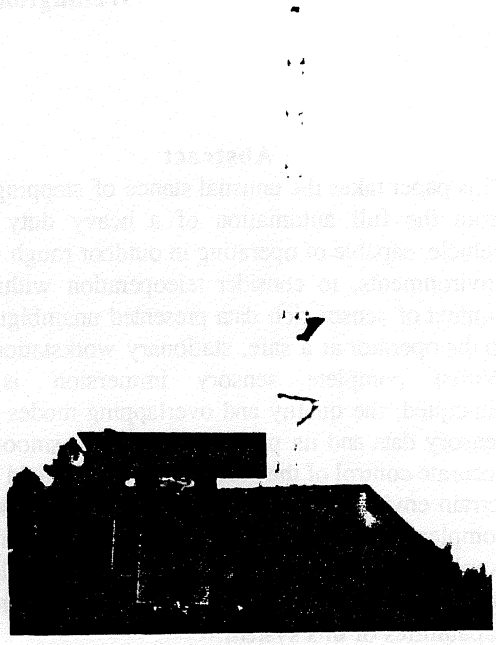

Figure 2.
G.P.S. Fixed Station and High Vantage Point Camera Tower with Mobile GPS Antenna in the Foreground.

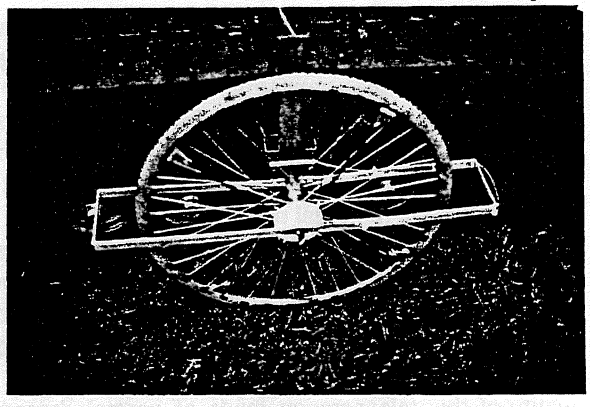

Figure 3.
Odometry Wheel.

A stereo video camera [See Figure 4] viewed remotely through a head mounted display [See Figure 5]by the operator allows a good appreciation of the spatial configurations of obstacles in the forward vicinity of the vehicle. However, stereopsis viewing is not a very helpful depth cuing mechanism beyond a few metres. An Erwin-Sick laser scanning time-of-flight rangefinder,

capable of returning range measurements at 1/2 degree intervals over 180 degrees in two seconds in a planar sweep, is mounted near the stereo camera [See Figure 4], both being attached to the wrist of a Puma 560 robot manipulator. This manipulator can be used to direct the gaze of the camera and rangefinder to allow a more exploratory mode of coverage. The rangefinder works up to 50 metres and is accurate to ±3cms. The obstacles discovered by the rangefinder can be marked into an environmental map constructed on a rectangularly tellelated grid. The shortest path to a nominated cell on this map, avoiding all obstacles so far detected, can be drawn on the map. A Distance Transform [4] based path planner was used for this calculation. The operator can drive the vehicle along this path or not as he/she chooses.

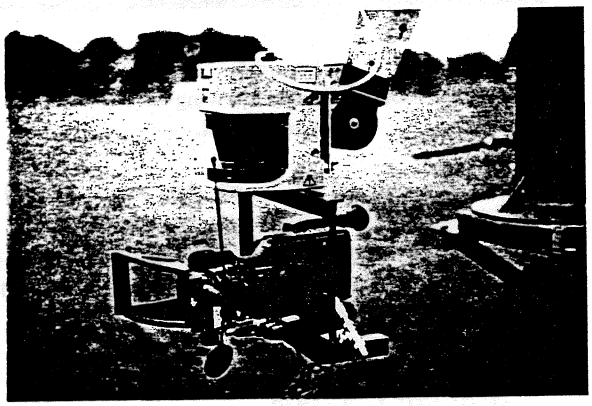

Figure 4.
Stereo Camera and Rangefinder Mounted on Puma 560 Manipulator Wrist.

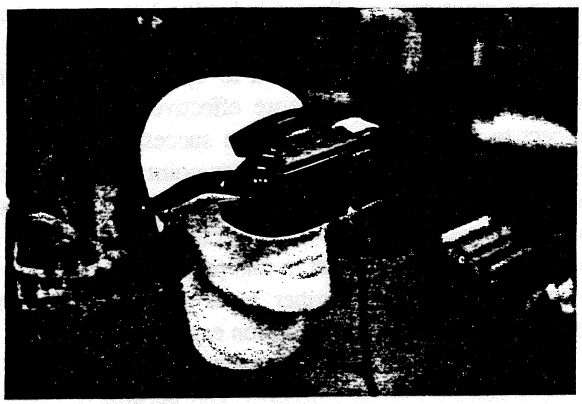

Figure 5.
Head Mounted Display.

Also mounted on the vehicle is a pitch/roll sensor which, in addition , contains a flux gate compass which can further support steering control actions by the operator (along with the odometry system and optical gyroscope).

This completes the testing of the sensors used to support teleoperation. Between them a very rich complement of sensor data is available, but unless this data can be presented to the operator in a clear and unambiguous way it will not be of much use.

A vital part of the system is the use of a radio ethernet link between the vehicle and a base station from which the teleoperation is directed. A pair of Aeronet radio ethernet units operating at 2 Mb data rate and a 8 port RS232 server, serve the communications need of the system, both for transferring sensor data from the vehicle to the base station and for control signals in the other direction. The radio ethernet link will operate over several hundred metres with standard antennae but the range can be extended up to 5km by using a more specialised directional antenna at the base station.

We had discovered through previous projects that there were a number of real advantages in operating a robot via radio ethernet instead of carrying all computational resources on-board. These included not having to carry a fragile and power consuming entity on-board, the convenience of being able to monitor operations on a screen at a stationary location, the ease with which any computer upgrade could be accommodated, the possibility that any suitable workstation in a local area network could take over the task of monitoring and controlling the remote vehicle and, finally, being able to control a fleet of vehicles from the one site. The second last of these would allow the time sharing of one vehicle amongst individuals working at their own workstation. Of course, there is also the advantage that the workstations can be used for other computational tasks as well as to monitor/control the robotic vehicle.

What is further added to the list of advantages when considering the teleoperation mode of control is that rich visualisation of the sensor data and the availability of easy to use driving controls are easily implemented on the controlling workstation. In our case, stereo viewing was via a see-through head mounted visor driven from a separate video transmitter; the high vantage point camera view could also be switched to the head mounted display. The see-through property of the visor allows the operator to view the controlling computer screen and operate the driving controls without taking off the visor.

The video from the stereo camera are in the form of field sequential multiplexed signals with the left and right eye views mixed in this way. A standard TV monitor picks up the signal and relays it to the stereo visor which includes electronics to demultiplex the left and right eye views to the appropriate eye pieces. It is also possible to use switching glasses to view this stereo image pair sequence on a large TV monitor if preferred. The switching gasses do not effect the views of the computer screen.

The driving controls are intuitively simple - a circular field with an arrow pointing out from the centre is displayed. The operator picks up the head of the arrow with the mouse and drags it anywhere within the circle; its direction determines the steering direction and its length

the speed. A dead zone near the center of the circle denotes a dead stop location. Pointing the arrow upwards directs the vehicle straight forward; downwards reverses the travel. Directly to the right drives the vehicle in an on-the-spot turn to the right with the tracks rotated in opposite directions; directly to the left drives the vehicle in a on-the-spot turn to the left. Intermediate positions adjust the left and right track speeds to enable any turning circle radius to be achieved both forward and in reverse. This simple steering/speed control aid has proven to be very easy to use. The size of the driving circle can be adjusted at will up to the whole screen size.

The G.P.S. location estimate can be shown on a separate map on the screen. The appropriate cell on the rectangularly tessellated map can also indicate this data but only the first map shows a trace of the track.

The odometry wheels and the optical gyroscope rotational data can be shown on circles on the screen. The pan/tilt/bearing data can be displayed as a needle whose direction of pointing in 3D indicates all three measurements simultaneously; the individual measurements are also shown on separate dials.

The raw data from the Erwin-Sick scanning rangefinder can be displayed in its own window at various selected scales and window sizes.

The operator can compare an impression conveyed by the stereo view regarding the 3D placement of obstacles forward of the vehicle with the rangefinder data which is both accurate and close to middle distance in scope (up to 50 metres).

The tracked vehicle is capable of negotiating rough terrain whilst pulling a considerable load. The roll/pitch data can give a clear indication of the slopes being negotiated and caution applied when appropriate.

Figure 6 depicts the workstation screen with a number of sensor displays shown. Included is the Erwin-Sick rangefinder data, two odometry wheel disks, the G.P.S. path tracking window, the pitch/roll/compass 3D pointer and the driving wheel. The path planning space and the optical gyroscope wheel are not shown. Any window can be expanded, repositioned or closed down at will. The operator can arrange whatever lay out best suits the task or fits in with personal preference. Video from the high vantage point camera can be viewed on a separate monitor or in a window on the computer monitor screen. The entire monitor screen can be replaced by a large back projection video screen if preferred.

The sensor data is gathered by software 'daemons' which scrutinise the various serial line channels on the 8 channel server on-board the robot. A common memory area is used to store this information for display and other purposes. Any process which needs sensor data knows just where to obtain the latest version. Not all 'daemons' need to be activated. Those that are activated utilise only a very small percentage of workstation processor time. This arrangement is both efficient and very convenient from a system developer's point of view.

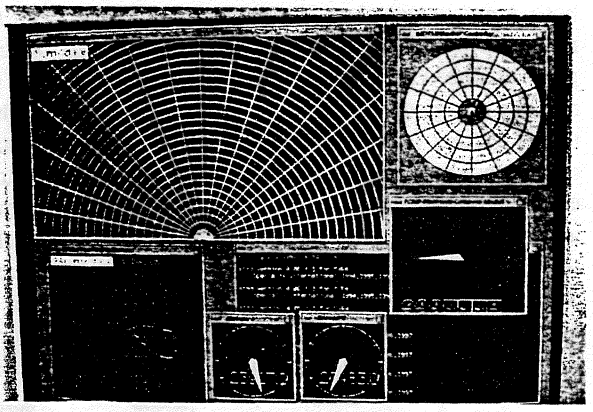

Figure 6.
Operational Monitor Screen Showing Sensor Data and Driving Wheel.

Overall, the rich set of sensor data available and the ease with which the vehicle can be driven makes the system potentially useful for fire fighting or demining or a number of similar tasks where sensor rich remote operation of a heavy duty vehicle is of value.

4. Preliminary Trials

So far we have teleoperated the robot vehicle on a playing field near the laboratory using mainly GPS and range data but not yet with the additional sensor data from a high vantage point camera. Stereo viewing became a problem when the video transmitter could not cope with the distance over which we wanted to operate; we have now experimented with other more effective transmitters and expect to be able to report more successful trials at the conference itself. The high vantage point camera had been used in earlier research so we know it is effective; however, we have to re-rig the cabling to set this up again. We see no problem in this part of the system. We also anticipate doing further trials on rougher, sloping ground to extend the teleoperation experience.

So far the experience has been very positive and the vehicle can be moved smoothly and accurately about its environment at varying speeds. Even though not all components of our system are fully in place it is clear that this mode of teleoperation is likely to be very successful. Video sequences will be shown at the conference to illustrate this success.

5. Future Developments, Discussion and Conclusions

Yet to be added is the human to robot manipulator control system which would allow the range sensor and stereo camera to be directed to view aspects of the environment

not accessible from a fixed position; such needs may arise in the vicinity of overhanging obstacles or where there are holes or trenches in the ground or where details of objects near the vehicle need to be scrutinised, as may be the case in defusing bombs or inspecting some plant in an agricultural operation. Adding a manipulator hand to the robot arm is also a possibility.

One approach to implementing robot arm/hand control would be to use a data glove with its Polhemus tracker to provide position and orientation data to specify the manipulator's pose, and finger closures to specify robot hand operations. The robot manipulator itself can be controlled via a serial data stream on an RS232 port on the serial line server on-board the vehicle. What is needed at the workstation end is a translator which takes in data glove data and converts it to VAL language strings to drive the robot.

Using the data glove may not always be convenient. An alternative would be to use a six degree of freedom joystick such as the Spaceball to control the manipulator; again a translator is needed.

The thin line between sensor rich teleoperation and autonomous navigation is not accidental in this case. We have deliberately exploited our interest in autonomous behaviour to produce an effective teleoperation system where human judgement can compliment instrumentation and computational components of the system.

Where more or less fully autonomous operation can be considered acceptable, for example, in ploughing a field or harvesting a crop, there still may be situations where unexpected events may be accommodated by inviting human intervention through teleoperation. The autonomous mode can be returned to after this temporary intervention. Examples might include the wandering of livestock across the path of the vehicle or the unexpected falling of a tree into a crop field. In a search and rescue operation, the search process might be almost entirely autonomous but the rescue operation itself may need a very customised touch according to the condition of the person being rescued. Human intervention would be important here lest a tragedy be caused at the brink of success of the search and rescue mission through not being sufficiently aware of the extent to which the being-rescued person is able to cooperate with the rescue process itself.

In conclusion, this paper has provided a description of a teleoperation system which can delicately control a heavy duty vehicle in rough terrain using autonomous navigation as the inspiration we have stopped one step short of, for this particular project. The key elements have been a plethora of instruments, stereo viewing and high bandwidth reliable radio based communications.

Bibliography

1.Jarvis, R.A. Mobile Robot Navigation, invited Plenary Address, Proc. Third Conference on Robotics, Melbourne, June 3-6, 1990,- pp.8-24.

2.Yagi, Y. Nishizawa, Y. and Yachida, M. Map Based Navigation of the Mobile Robot Using Omnidirectional Image Sensor COPIS. Proc. 1992 IEEE International Conference on Robotics and Automation. Nice, France, May 12-14, 1992, Vol.1. pp.47-52.

3.Lozano-Perez, T. and Wesley, M.A. An Algorithm for Planning Collision-Free Paths among Polyhedral Obstacles, Commun. ACM, Vol.22, No.10, pp.143-148.

4.Jarvis, R.A. On Distance Transform Based Collision-Free Path Planning for Robot Navigation in Known, Unknown and Time-Varying Environments, invited chapter for a book entitled 'Advanced Mobile Robots' edited by Professor Yuan F. Zang, World Scientific Publishing Co. Pty. Ltd. 1994, pp.3-31.

5.Brooks, R.A. Solving the Find-Path Problem by a Good Representation of Free Space, IEEE Trans. on Systems, Mana and Cybernetics, SMC-13, No.3, pp.560-570.