Proc. 2002 Australasian Conference on Robotics and Automation
Auckland, 27-29 November 2002

An Articulated Six Wheel Drive Robot for Very Rough Terrain Navigation

Ray Jarvis
Intelligent Robotics Research Centre
Monash University
Clayton, Victoria, 3800, Australia
Ray.Jarvis@eng.monash.edu.au

Abstract

This paper concerns the design, construction and instrumenting of a six wheel drive, articulated mobile robot capable of very rough terrain navigation. Navigation strategies current and in development, are also presented. Video clips of the vehicle in operation will be presented at the conference.

1. Introduction

It is clear that when robots move out of structured environments associated with classical factory environments, richer sensor instrumentation and more powerful Artificial Intelligence methodologies are needed to deal with the uncertainties and time-varying aspects of natural, unstructured environments. Mobile robots designed to operate in indoor, flat floor environments which have been set up with beacons are relatively easy to control. Those required to operate in outdoor settings, particularly initially unknown, rough terrain and time-varying environments, must deal with much more complex issues. Such systems must generally exploit the data redundancies provided by multiple sensors to manage such complexities and contain errors of localization and mapping, whilst simultaneously providing highly reliable, low risk operations and graceful recovery procedures.

Rough terrain operation also requires, somewhat obviously, the capability of mechanically negotiating the terrain through a combination of avoidance and climbing ability. Whilst legged and flying machines have obvious advantages over wheeled vehicles in this respect, they are more expensive to build and more difficult to control. Wheeled machines also have the capability of rough terrain traversal if appropriately designed mechanically, including the structure of the chasis, the powering of the wheels and choice of the steering system.

This paper deals with the design, construction and instrumenting of a six wheel drive vehicle with an articulated chasis. The vehicle can negotiate obstacles of the size of its own wheels (20 inches in diameter) and turn on the spot. Current tele-autonomous navigation capabilities are also described along with ideas on fully autonomous operation currently under development.

The following sections deal with the mechanical structure, energy resources, instrumentation and navigation strategy, in turn. The last section provides a brief summary of what has been achieved and what is yet to come in the near term future.

2. Mechanics and Power Train

Figure 1 shows several views of the robot which is the size of a small car, just a bit larger than a golf buggy. It is 2.5 metres long and 1.7 metres wide. The chassis design was inspired by a Russian built, half scale working model of a Marsokhod Mars Rover (M96) [see Figure 2] which has been used in the Intelligent Robotics Research Centre at Monash University since 1997.[1] Each axel can rotate around the longitudinal axis independently and a mid body joint permits passive articulation around a horizontal axis approximately aligned with the mid axel [see Figure 3]. The central structure is maintained at the bisecting angle between the front and rear components by sliding braces on a vertical bar. This not only stabilizes the centre axel so that ground torque can be applied through the middle wheels but also keeps any instruments on the central portion less subject to the ‘bucking’ of the vehicle through this pitch ‘averaging’ effect.

Figure 1(a) - Side View Instrumented 6WD Articulated Robot Vehicle

Each wheel (approximately 20 inches diameter) is driven by its own electric motor gear set (wheelchair system) through a 3:1 gear reduction provided by a chain drive. The motors are mounted well above the ground and the vehicle can be submerged to a depth of 60cm (can be extended to 1 metre with adjustments). The vehicle is rigid with regard to rotations about a vertical axis and is skid steered through differential right and left set wheel torque. It can turn around its midpoint. The chasis is constructed entirely out of steel pipe and is perhaps heavier than need be, but this design is sufficient for the 'proof of concept' experiments intended.

Figure 1(b) - Front View Instrumented 6WD Articulated Robot Vehicle

3. Energy Resources

The six electric motor/ gear sets are driven using a standard wheelchair controller normally operated using a joystick. The motors use a 24 volt DC supply from a pair of car batteries. The same batteries are used for all instrumentation and computer power using 24 to 12V DC to DC converters, 12V to 240 AC (pure sine wave) converters and power packs. This means that, in the lab, all instrumentation are computers can be mains power driven for convenience.

Two separate means of continuously charging the batteries during lengthy field trials have been provided. Without such systems the estimated operating time on a simple pair of 12V batteries would be under one hour. A 400 watt 24V wind generator can be mounted 3 metres above the ground by attaching its mounting pole to the vehicle instrument bar [see Figure 1(a)]. This unit has its own charging regulation system and can be left running continuously. If there is insufficient wind velocity, a 50 amp/ 24V petrol generator can be used instead, thus permitting several hours of operation without providing an auxiliary petrol tank. When the generator is operating one can regard the robot vehicle as a petrol/ electric system, the generator providing the energy and the electronic motors the power distribution to each of the six wheels without mechanical drive shafts being needed (such shafts would be complicated to provide, given the articulation of the chasis).

Figure 1(c) – Close Up Gyro Stabilised Sick Rangefinder

4. Instrumentation

Figure 4 shows the instrumentation provided on the vehicle. There are three categories of the way the instrumentation is deployed. Firstly, there is a colour video camera mounted on top of an Erwin Sick laser rangefinder at the front of the vehicle [see Figure 1(c)]. Its signal is sent to a multiple diversity antenna system at the 'home base' via a high quality radio transmitter. This camera can be used by a teleoperator to see what is in front of the vehicle and perhaps compare the image with the horizontal range scan of the Sick rangefinder. Secondly, the Sick rangefinder is connected to an on-board Silicon Graphics workstation; this machine controls the velocity and steering of the vehicle via a microprocessor which takes over the function of the standard joy stick used on the wheelchair which the motor/gear/ PID controller system was designed for by the wheelchair manufacturer. A low-level reaction mode and a mid-level mode of obstacle avoidance are implemented on this on-board computer so that a loss of communications with the 'home base' systems need not be a disaster. Details of this strategy are provided in Section 5. Radio Ethernet with a line-of-sight range of 4 km is used for the link between the vehicle and 'home base'. A serial line server collects of instrument data and streams this either to the onboard computer or to the 'home base'. Included are a differential/ phase mode Global Positioning System (GPS) capable of 20cm accuracy, an optical gyroscope to support steering, a web cam for general use and a pitch/roll/bearing sensor. A long range (300m) laser rangefinder mounted on a pan/ tilt mount make up the third class of instruments. A 'turnkey' system on a personal computer is used to collect scanned range data on command. The 'turnkey' system collects scan parameter details from a nominated machine on the network (can be the on-board machine or any other on the network, including the 'home base' machine) and carries out the scan process, informing the commanding machine when the task is completed, (including transmitting the scan data results) by clearing the original command parameter file. This 'hand shaking' process makes scan data collection very easy. Typical scans collect 640,000 range values over a 300° azimith and 60° elevation scans, each value of approximately 10cm range resolution up to a distance of 300 metres. Figure 5 shows such a scan; this took approximately 7 minutes to collect. Both laser rangefinders are mechanical gyro stabilized and can maintain an upright pose despite pitch and roll movements of the robotic vehicle. For the long range unit on its own pan and tilt head [see Figure 1(d)], the shift of the centre of gravity whilst a scan is in progress is a serious problem for the gyroscope system. A simple solution is to consider the gyroscope as a pitch/ roll rotation dampening mechanism and to clamp the axes of the gyroscope platform when laser scanning is actually in progress, with the vehicle stationary. This is not an issue for the Sick rangefinder since it scans in a single horizontal sweep using a spinning mirror. No low frequency change of the centre of gravity is noticeable. This means that the Sick rangefinder can be used continuously to provide the reaction and mid-level modes of obstacle avoidance whilst the vehicle is in motion, even over bumpy ground.

Figure 1(d) - Close Up 300m Range Scanning Laser Rangefinder (also Gyro Stabilised)

5. Navigation Strategy

The notion of a three level navigation system, has been 'migrated' from earlier projects, where the top level was provided by the user whether on-board [2, 3] the vehicle or tele-operating it at a distance.[4] The middle level system analyses range data from the Sick rangefinder and uses a distance transform strategy [2] to determine the safest way forward over the next few metres [Figure 6 shows such a determination]. Details are provided in [2]. For the wheelchair project [2, 3] the user could over-ride the 'advice' given by this middle level analysis if fully capable of navigating safely without it. However, after a number of near miss collision situations, the 'advice' is used to modify the user's 'intention' towards a safer passage. The lowest level system is a pure reaction one which slows the vehicle to a stop as it nears an obstacle in front and causes it to veer away from side obstacles if they are approached too closely. Figure 7 captures the concept of this three level control system.

Figure 2 - Half Scale Working Marsokhod M96 Mobile Robot

For the current project, the plan is to replace the human user's immediate steering and velocity intentions with a global path planning result provided through the analysis of environmental mapping data captured by the long range scanning laser rangefinder. An initial detailed scan (taking some minutes) will provide a starting map. This can be added to and adjusted using directed range scans during navigation. If necessary, the planned path will be updated and the excursion continued to completion (e.g. reaching a specified goal).

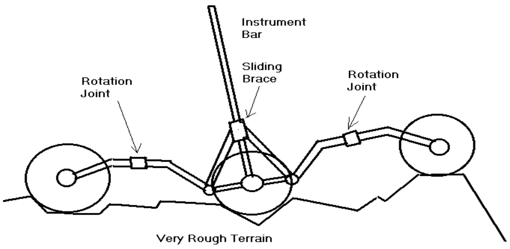

Figure 3 - Chasis Configuration

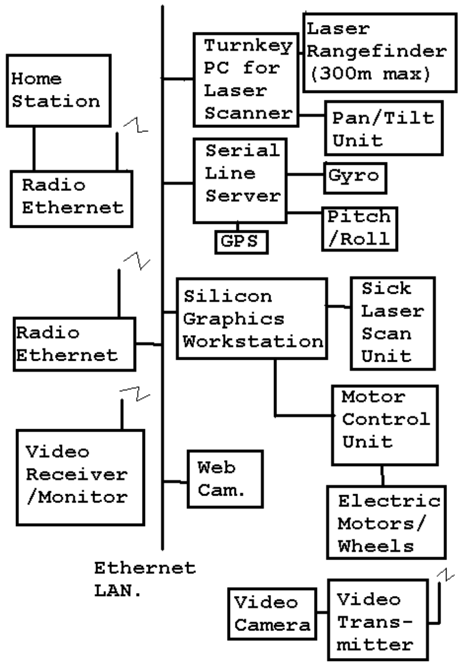

Figure 4 - Instrumentation Schematic

The distance transform (DT) methodology [5] that has been used successfully in previous projects [6, 7] may not be ideal for high resolution large scale planning due to the computational load involved in filling all of free space with integers indicating the number of cell steps to the goal (e.g. over a 1000 x 1000 rectangular tessellated space). The use of rapidly exploring random trees (RRT) [8, 9] in tessellated space looks like a promising way to go. The RRT method grows branches from two existing tree nodes, one tree root being at the start point and the other at the goal. A uniformly random point in search space is generated and joined to the nearest node of each of the two trees if the vehicle can bridge these gaps. Otherwise, a greedy strategy adds (to each tree) a node along the path from the nearest node to the random point until the point itself is reached or an obstacle is encountered along the way. A typical RRT structure is shown in Figure 8. The procedure ends either when a specified number of nodes have been generated or when any node in the tree is close and reachable with respect to any node of the second. In real space, the search for the nearest nodes of existing trees to the random point can be computationally expensive and this cost increases as the number of nodes generated increases. In tessellated space, more efficient, propagation based searches for the nearest nodes can be carried out and this cost decreases as nodes proliferate [10]. The computational savings can be quite significant. One particularly helpful property of the RRT method is that random points are more likely to be generated in large open (as yet unexplored) spaces than cramped spaces since the selection is uniformly random. This accounts for the aggressive exploration behaviour of this approach. This methodology finds feasible but not necessarily optimal (say shortest) paths and tend to produce some 'ragged' sections along the discovered path This 'raggedness' can be smoothed out by applying Distance Transforms in strips of tessellated space straddling the RRT path. It may also provide a combination of short, smooth and safe paths approximately following the path provided by the RRT. The distance transform analysis can also take into account the cost of entering cells on the basis of local tractability (slope, small rocks, etc). Initially, GPS can provide the needed localization fixes, but in the longer term the environment itself can provide the localization landmarks.

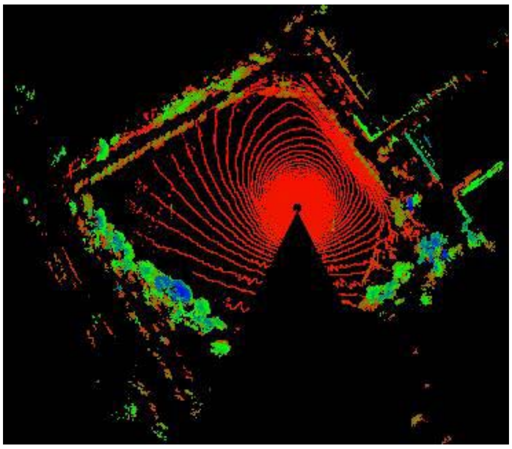

Figure 5 - Typical Long Range Laser Rangefinder Scan

Figure 6 - 'Advice' on Local Safe Direction

6. Discussion, Future Work and Conclusions

The vehicle described above is now complete and all instrumentation installed. The basic tele-operated control system is undergoing field testing, but the global path planning phase has not yet begun. Of particular interest are the means by which new range data may be integrated with the starting map, the effectiveness of smoothing out RRT paths using Distance Transforms, and the testing of the 3D environmental map data as a source of natural landmark localization cues. With regard to the last of these, images from a colour camera mounted on the long range laser scanner are being registered with the range data to colour render the whole map as an aid to discovering natural landmark candidates.

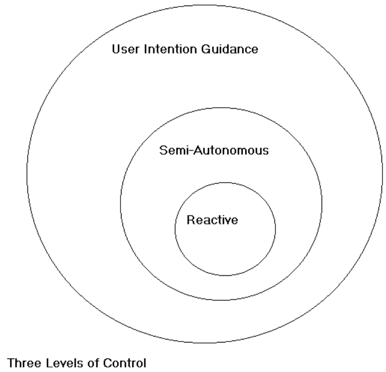

Figure 7 - Three Level Control Strategy Schematic

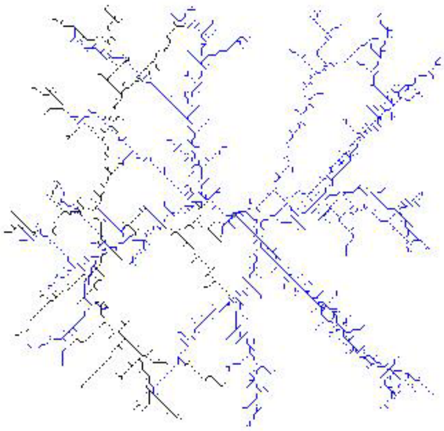

Figure 8 - Typical RRT Structure

This project promises to provide a solid platform for concept testing navigation experiments in very rough terrain, but the fruits of this hope are yet some months off. Potential application domains for such a vehicle include search and rescue missions, mineral exploration and bush fire fighting support.

REFERENCES

[1] Jarvis, R.A. Autonomous Navigation of a Martian Rover in Very Rough Terrain, Proc. International Symposium on Experimental Robotics, March 26-28, 1999, Sydney University, pp.225-234.

[2] Jarvis, R.A. A Vision Assisted Semi-Autonomous user-Adaptive Rough Terrain Wheelchair, Proc. 4th Asian Conference on Robotics and its Applications, 6 - 8th June, 2001, Singapore, pp.45-50.

[3] Jarvis, R.A. A Go Where You are Looking Semi-Autonomous Rough Terrain Robotic Wheelchair, accepted for presentation at the First International ICSC Congress on Autonomous Intelligent Systems, Deakin University, Geelong , Australia, 12-15 Feb. 2002.

[4] Jarvis, R.A. A Tele-Autonomous Heavy Duty Robotic Lawn Mower, Proc. Australian Conference on Robotics and Automation, 14,15th Nov. 2001, Sydney.

[5] 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.

[6] Jarvis, R.A. and Lipton, A.J. GO-2 :- An Autonomous Mobile Robot for a Science Museum, Proc. 4th International Conference on Control, Automation, Robotics and Vision, Westin Stamford, Singapore, 3-6 December, 1996, pp.260-266.

[7] Jarvis, R.A. An Autonomous Heavy Duty Outdoor Robotic Tracked Vehicle, Proc. International Conference on Intelligent Robots and Systems, Grenoble, France, Sept. 8-12, 1997, pp.352-359.

[8] La Valle, S.M. Rapidly-Exploring Random Trees: A New Tool for Path Planning, Iowa State University, October, 1998.

[9] Kuffner, J. J., and La Valle, S. M. RRT – Connect: An Efficient Approach to Single-Query Path Planning, Proc 2000 IEEE International Conference on Robotics and Automation, San Francisco, April, 2000, pp 995-1001.

[10] Spero, D. J., and Jarvis, R. A., Path Planning for a Mobile Robot in a Rough Terrain Environment. In Third International Workshop on Robot Motion and Control, Bukowy Dworek, Poland, 9-11 November, 2002. IEEE In Press.