A ‘Do-it-Yourself’ Segway Mobile Robot Platform

Ray Jarvis
ARC Centre for Perceptive and Intelligent Machines in Complex Environments:
Intelligent Robotics
Monash University
Ray.Jarvis@eng.monash.edu.au

Abstract

This paper concerns the adaptation of a Segway electric scooter for mobile robot navigation work and its instrumentation in preparation for these experiments, potentially aimed at security applications where its speed and dexterity are of distinct value.

1. Introduction

When choosing a platform for mobile robot navigation work many considerations come to mind. These include operational domain (indoors/outdoors, on the ground, under or on water, in the air, hostile environments etc.), payload, mission period, cost, control simplicity and so on. For on-the-ground (rough terrain), tracked or legged vehicles may be favoured. For tight spaces, say indoors, snappy turns and small footprints may be favoured. For control simplicity a two wheeled, differentially steered vehicle with castor wheel stabilisation is very popular for smooth flat surfaces. However, the size and bias (flip when there is a change of direction) of the castor can be a problem when less than smooth surfaces are to be covered.

The Segway [http://www.segway.com, Figure 1] has a number of interesting features which promote it as a good choice for a robot platform for a number of operational domains. It also has some weaknesses. The machine is fairly inexpensive (US$4,495) from a robotics point of view. It can carry a pay load of a human (say up to 118 kilos) for in excess of 12 miles at a maximum speed of 12.5 mph. For lower speeds and payloads it can probably (not yet tested) operate for a number of hours between battery recharges. It is silent, non-polluting, can pass through a door fashioned for humans and turn on the spot. Its wheel size of 48cm diameter permits it to operate both indoors and out (in medium roughness terrain – say a paddock). The Segway is differentially steered (with two drive wheels) but needs no stabilising castor since it balances by continuously solving the inverted pendulum problem in one dimension (forward and backward). A human passenger simply leans forward or backward from a standing position to control the forward or backward acceleration, respectively. A handle-bar mounted rotatable wheel (like an throttle on a motor-bike) controls the steering turn velocity clockwise or anti-clockwise. The machine takes most humans just a few minutes to feel comfortable with driving it.

Figure 1. Segway Scooter for Personal Transport.

This paper is about adapting a Segway to become a robotic platform for indoor/outdoor navigation which can match human speed, potentially for security based applications. Note that a robotically modified version of the Segway has been recently offered on the market (Segway RMP ≈US$15,000; created for the US Defence Advanced Research Projects Agency) for three times the basic cost of the machine. Here is shown how to avoid this mark up quite simply.

Whilst it can be argued that, compared to the cost of sensor instrumentation, communications and computational support, this cost is acceptable, it remains the case that the possible redevelopment of these additional items over other experimental robotic projects reduces the per project cost and thus the cost of the platform itself is a significant factor in affordability.

There has been a considerable amount of previous research on balancing mechanisms with one or two wheels [0] which have been considered as mobile robot bases. These are deliberately not considered here because the emphasis is on using off-the-shelf affordable platform where the balancing control is already provided and, in fact, does not need to be understood to get the results shown in this paper. This is one of the main aspects of this paper.

The instrumentation deployed on the machine in preparation for navigation experiments is also described.

2. A Balanced Approach

Without knowing anything about the componentry of the Segway, it is obvious that changing the position of the centre of gravity of the payload could control the forward/reverse acceleration of the vehicle. One could naively imagine sandbags on horizontal linear bearing rails being servoed along the rails using remote controlled motors and pulleys. If one thought about it more carefully, one could come up with the bright idea of replacing the sandbags by batteries which would in any case be needed for the instrumentation or could extend the running time of the vehicle. Turning the steering knob using a small motor and pulley chain is trivial. All a bit primitive but straight forward. So is this what was done? No.

The Segway has a small yellow plastic box like structure about 9cm cube containing two electrolyte fluid tilt sensors and five angular-rate gyros. This is the sensor intelligence used by the control electronics to control the inverted pendulum problem. Fortunately, this ‘box’ can be extracted from the bowels of the base of the Segway (with wiring still attached) and manipulated to ‘trick’ the Segway regarding the direction of the vector from the centre of gravity to the point of ground contact support (in one dimension). By mounting this device to allow it to rotate a few tens of degrees (± 30º) about a horizontal axis parallel to the wheel axle and close to it physically, one can control the forward/reverse acceleration by tilting the box backward/forward, respectively, using a simple hobby style servo motor [see Figure 2].

Figure 2: Tilt Sensor/Rate Gyro Assembly Control.

Thus the first trials of this approach allowed two servos to control the Segway using a simple hobby style radio control transmitter. A little practice is needed but the result is very satisfying. The servos will soon be driven from a microprocessor with a serial (RS232) link to an on-board computer or via a serial line server and radio Ethernet to an off-board computer.

3. Instrumentation

The instrumentation configuration is shown in Figure 3 and the adapted Segway itself in Figure 4. Note that ‘training wheels’ which do not touch the ground under normal drive have been added for safety.

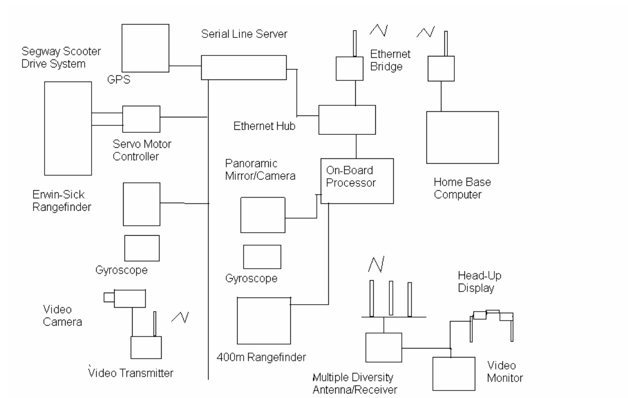

Figure 3: Instrumentation Schematic

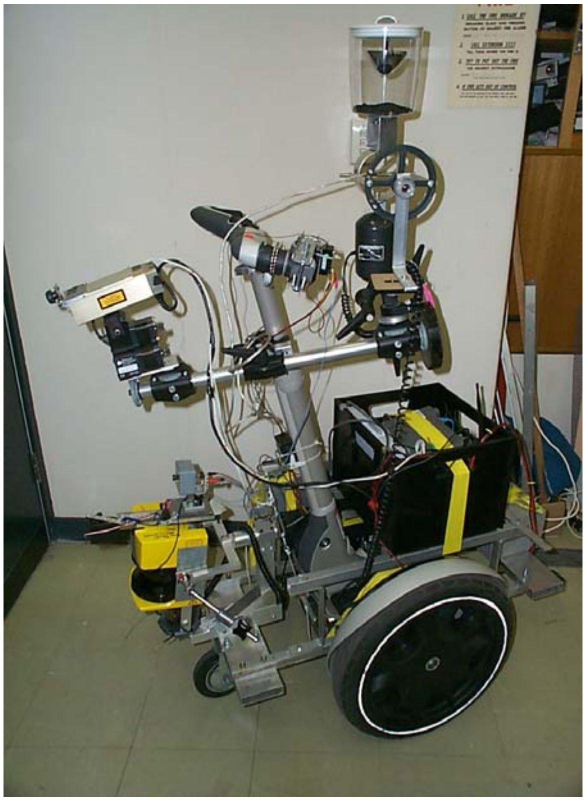

Figure 4: Robotically Instrumented Segway Scooter

One of the problems with using a Segway as a robot platform base in the fashion described above, is that the body of the vehicle tilts forward and backward as the machine moves, thus subjecting fixed on-board sensors to the same motion. For cameras and rangefinders this could be a serious disadvantage unless compensated for. A simple correction can be provided using steady-cam type mechanical gyroscopes. A Sick laser rangefinder, with a colour video camera on top of it has been so stabilised. This sensor pair remains pointing in a horizontal direction if so set as the vehicle moves forward or in reverse. Since these instruments are not at the centre of steering rotation some disturbances are felt as the vehicle turns, but these are to some extent damped by the gyro. To allow both the rangefinder and the camera to look up or down from a horizontal pose, the centre of gravity of the gymble mounted instruments is shifted back and fourth using a third servo motor and a weight. The instruments stabilise to their new poses fairly quickly in a damped steady movement [see Figure 5].

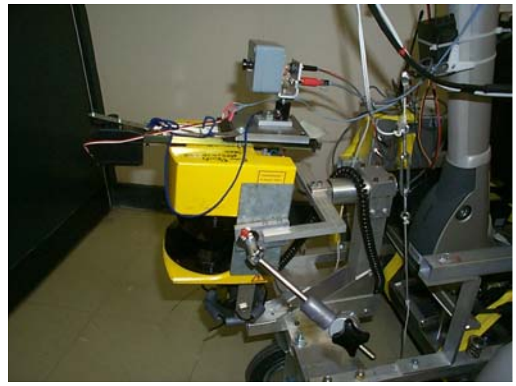

Figure 5: Gyro Stabilised Erwin Sick Laser Rangefinder with Tilt Control

A radio Ethernet bridge unit with a 4 kilometre range is used to link the Segway to an off-board controlling machine. The camera on top of the rangefinder is linked to the base station using a high quality video transmitter and multiple diversity antenna system. Other Ethernet cameras can also be used but their image update speeds do not come up to the full frame rate (30 frames/sec) of the analogue camera.

A panoramic mirror provided by Professor Srinivasan of the Australian National University (who is a Chief Investigator in our ARC Centre) and its camera are also gyro stabilised [see Figure 6]. The use of panoramic views for localisation and mapping is planned as is the inclusion of a 400m range laser range finder mounted on a pan-tilt mount already developed in the Centre [Spero and Jarvis, 2002]. A number of previously developed path planning strategies [Jarvis, 1994, Tang and Jarvis, 1992 and Kuffner and La Valle, 2000] are candidates for use on this project as are newly developed path planning strategies designed specifically for covert operations [Marzouqi and Jarvis, 2003] and take obstacle avoidance, observability and efficiency into consideration.

Figure 6: Gyro Stabilised Panoramic Mirror and Video Camera

A phase/differential mode GPS system developed for earlier projects [Jarvis, 1997] is intended to be used on this project for open outdoor environments.

4. Experimental Results and Future Work

Testing the manoeuvrability of the Segway under radio controlled operations has indicated good promise for fully automated control, the movements, both linear and curved, being both smooth and responsive to command. Putting the machine under computer control using a serial line (RS232) driven servomotor controller should be straight forward. The capture of both Sick rangefinder data and scans from the 400 metre range laser rangefinder [see Figure 7] have already been achieved. Some work on analysing panoramic views using Evolution Robotics vision demonstration software already shows promise for panoramic vision based localisation.

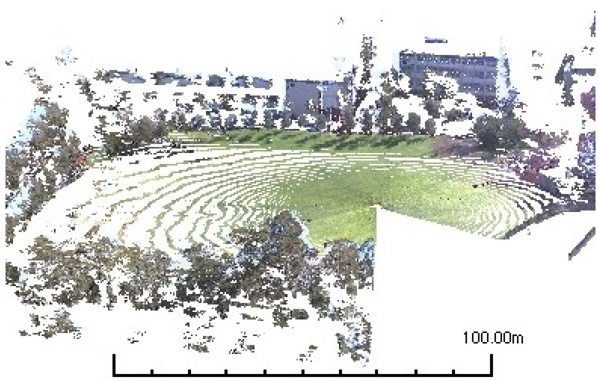

Figure 7: 2D Scanning Laser Rangefinder Scan (with Colour)

Putting the whole system together still remains to be done.

Once basic navigation has been achieved, the hope is to combine this capability with that of surveillance monitoring systems to enhance the effectiveness of the surveillance system itself and, simultaneously, provide appropriate robotic intervention with regard to minimising the human risk of crime and terrorist act prevention and reaction.

Conclusion

This paper has shown how to convert a Segway scooter into a mobile robot in a simple but effective manner and has detailed its instrumentation towards developing it as a security robot working within the context of a video surveillance system.

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