Technical Milestone Report

Robotic Unicycle:

Electronics & Control

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www.roboticunicycle.info

1 Abstract

In a joint project with Mark Mellors (Pembroke College), a remote-controlled Robotic Unicycle is being designed and built, and a control system is being developed. This milestone report concentrates on the electronics and software aspects of the project. The aims of the project, the plan to achieve those aims and the progress to date are reported.

2 Introduction

A unicycle is a simple mechanism but an unstable system and a complex control problem. The building of a robotic unicycle that mimics human behaviour has never adequately been achieved. This project sets out to achieve it. A main drive wheel and an inertial ‘disc’ (representing the rotation of the arms and torso of a human unicyclist) will be the only two outputs of the system. The control of movement in five directions (yaw, pitch, roll, x, and y) using only these two outputs will demand an understanding of mechanical interactions that are not easy even for a human rider to learn. Software control, provided by an on-board computer, is required and various sensors will gather information about the state of the unicycle. The unicycle’s speed and direction will be remotely controlled (like a radio-controlled car), but the finished unicycle will be autonomous with its power supply, sensors and computer control all mounted on-board.

3 Aims

Riding a unicycle is a complex control challenge. The Robotic Unicycle project hopes to further the understanding of how such a system is controlled: both by humans and by electronic means. A major goal of the project is to design and build a functioning Robotic Unicycle. Modelling of the system will be undertaken, but the project hopes to provide insights into applied control theory and develop a better understanding of real control problems. The hardware of control systems and their interfaces will need to be explored in depth, as the building of a robotic unicycle presents many design choices. The project involves working in a team and contributing knowledge from academic study of electronics and control, towards a definite result that meets deadlines and budget requirements. It is intended that the finished Robotic Unicycle will act as a platform for future experiments in control (particularly involving learning algorithms) and it may also be entered into robotics competitions.

The electronics for the Robotic Unicycle should be invisible, integrated, robust and reliable. A mixture of analogue and digital electronics will be required, accompanied by some electrical circuits for on-board power supply. It is worth remembering that, although design and build of electronics may be required, the aims of this project are of control of the unicycle rather than electronic design.

Overall control of the Robotic Unicycle will be achieved in software. The software should therefore be designed to be as flexible as possible so that different control methods can be easily tested. The software will need to interpret signals from various sensors – including demands requested from a radio remote control. The software, given information from the sensors, will need to determine what state the unicycle is in and how to respond.

4 Plan

There is a great deal to be achieved if the project is to be successful.

The main structure of the Robotic Unicycle was designed and built in June 2004, before the official start of the project. This allowed work to commence immediately with the mechanics and computer modelling of the control system. Research was undertaken at an early stage – which helped define the scope and feasibility of the project – allowing thorough investigation of the design alternatives (particularly the control system and sensors).

An early brainstorming session determined that all systems should be on-board and a computer controller would be required, interfacing with sensors, actuators/motors and radio control receiver. With these expectations in place, a process was outlined for the electronics and software aspects of the project and this is summarised in Figure 1.

Assessment **Budget** **Fundraising** **Website** **Research** **Control Development** **Logbook**	**Phase One:** *Specification & Design* Determine variables Determine sensors Determine controller & system requirements Determine behaviour of sensors Design of software and circuits **Phase Two:** *Implementation* Build and test circuits Interface sensors with controller **Phase Three:** *Control Development* Develop control software Balance unicycle in pitch axis Develop control software Balance unicycle in roll axis Extensive testing

Figure 1: Project plan showing continuous work and phased work (roughly corresponding to university terms).

The project is managed using a Gantt chart and a website. The Gantt chart allows tasks to be broken down and split between the team, with set targets that allow progress to be monitored. The project website aids communication and is used to record ideas, research, experimental results and to store designs, photographs and datasheets. Minutes of meetings and supervisions are recorded there for quick reference.

Budget rapidly became a concern, with the cost of building a unicycle greater than the allocated budget for the project. Fundraising activities used illustrations of early progress and invited potential sponsors to view photographs on the website. In December 2004, British Telecom confirmed an award of £1,000 for the Robotic Unicycle project.

5 Progress

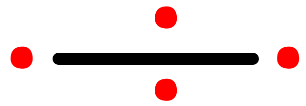


Figure 2: Range finder arrangement around the unicycle wheel.

Research has been conducted into pendulum sensors; tilt switches; gyroscopes; solid-state gyroscopes; ultra-sonic, infra-red and laser range finders; magnetic compasses; tachometers; accelerometers; and radar/sonic positioning systems. It was decided that four infra-red range-finding sensors, measuring distance to the ground and positioned as shown in Figure 2, would be used as 'low-frequency' sensors that can indicate the position of the unicycle relative to the vertical. Three small accelerometers, measuring changes in yaw, pitch and roll, would be used as 'high-frequency' sensors. Additional sensors will be used to measure the speed of the wheel and disc.

A sample analogue output infra-red range finder was tested using the inverted pendulum apparatus to confirm its suitability. The light sensor measured distance to a smooth reflective surface on the carriage of the inverted pendulum, which was then demanded to move certain distances at various velocities. Results were recorded on computer for comparison to the manufacturer's datasheet. Figure 3 shows the manufacturer's chart plotting analogue output voltage against distance, and it shows a single curve. Figure 4 shows the same chart using the data collected from the experiment: two curves can be seen. It was found that, at speed, the sample rate of the range finder limited the accuracy of the distance measurement. When the distance was decreasing, the delay in the range finder gave a result that showed the distance was larger than it was (and vice versa). This is an interesting effect but does not pose a significant problem because the software can adjust for this degree of error. Outliers, possibly from specs of dust or an unclean surface, are more of a concern as any statistical interpolation to remove these errors could limit the unicycle's performance on rough ground. The results were, however, acceptable and the data from these experiments can be used to interpret the analogue voltages from the sensors to give distance measurements.

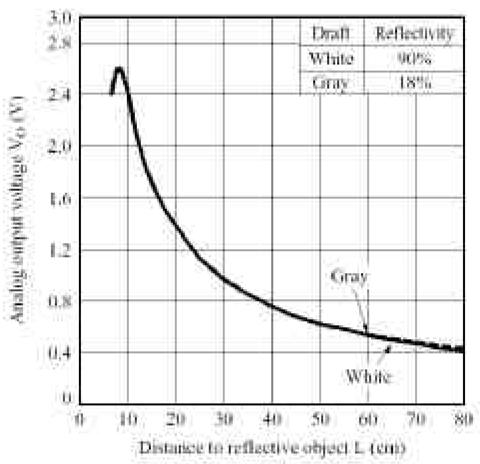


Figure 3: Chart from Manufacturer's datasheet for infra-red range-finder (courtesy of Sharp Europe).

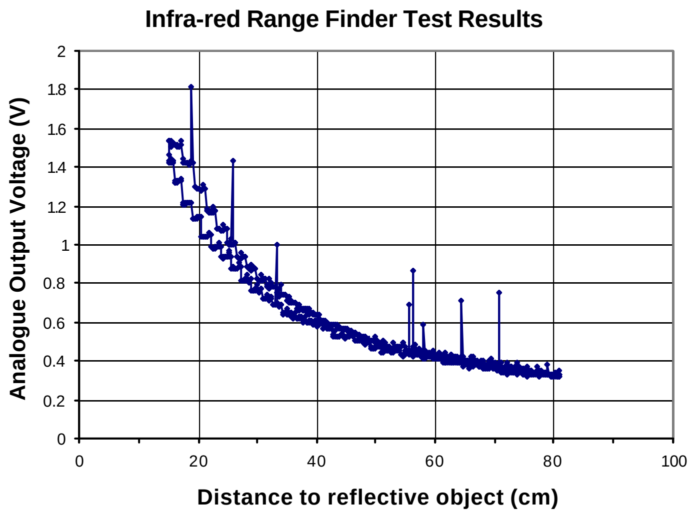


Figure 4: Results from experiment with the infra-red range finder. The chart gives a better understanding of the real data likely to be collected.

The accelerometers were tested on a unicyclist attempting to balance on the spot. The magnitude of variations in the signal was significant, although there were changes due to drift (hence there use at 'high-frequencies'). A simple 30Hz low-pass filter was needed to clean the signal for viewing on an oscilloscope but this did introduce a delay onto the signal.

Four drive system alternatives, shown in Figure 5, were identified and compared for cost, response time, bandwidth and so on. Electronic Speed Controllers (ESCs) were required in each case, and option 3 was determined to be the most promising solution for further development.

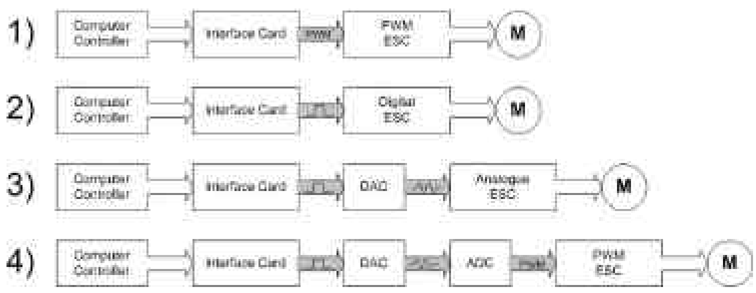


Figure 5: Four options for the motor drive systems.

Research into a computer controller eliminated PICs, FPGAs and other electronic solutions. A software-based approach was preferred, and work was conducted on a solution involving a Personal Data Assistant (PDA) such as the HP iPAQ that could be mounted on the unicycle. A USB interface card was found at low cost and offering great flexibility. Connections would be made to sensors via ADCs and DACs, with direct connection to digital signals. Initial trials of C++ code proved to be successful at connecting to the USB interface card. Page 6 shows diagrams of the electronic-system level design for the Robotic Unicycle's sensors, inputs and outputs, based on this solution.

An alternative computer controller was then recommended. National Instruments have recently launched a product called 'Compact RIO' and offered a free sample – see Figure 6. This equipment was not considered earlier because of its high cost. Compact RIO offers a microprocessor controller that interfaces internally with signal conditioning electronics – allowing direct connection to the sensors.

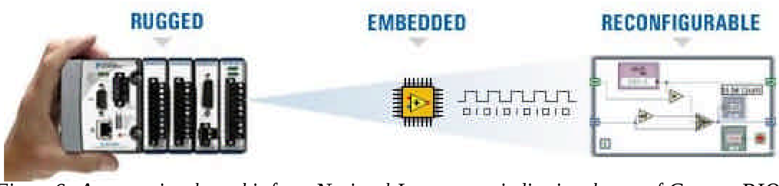
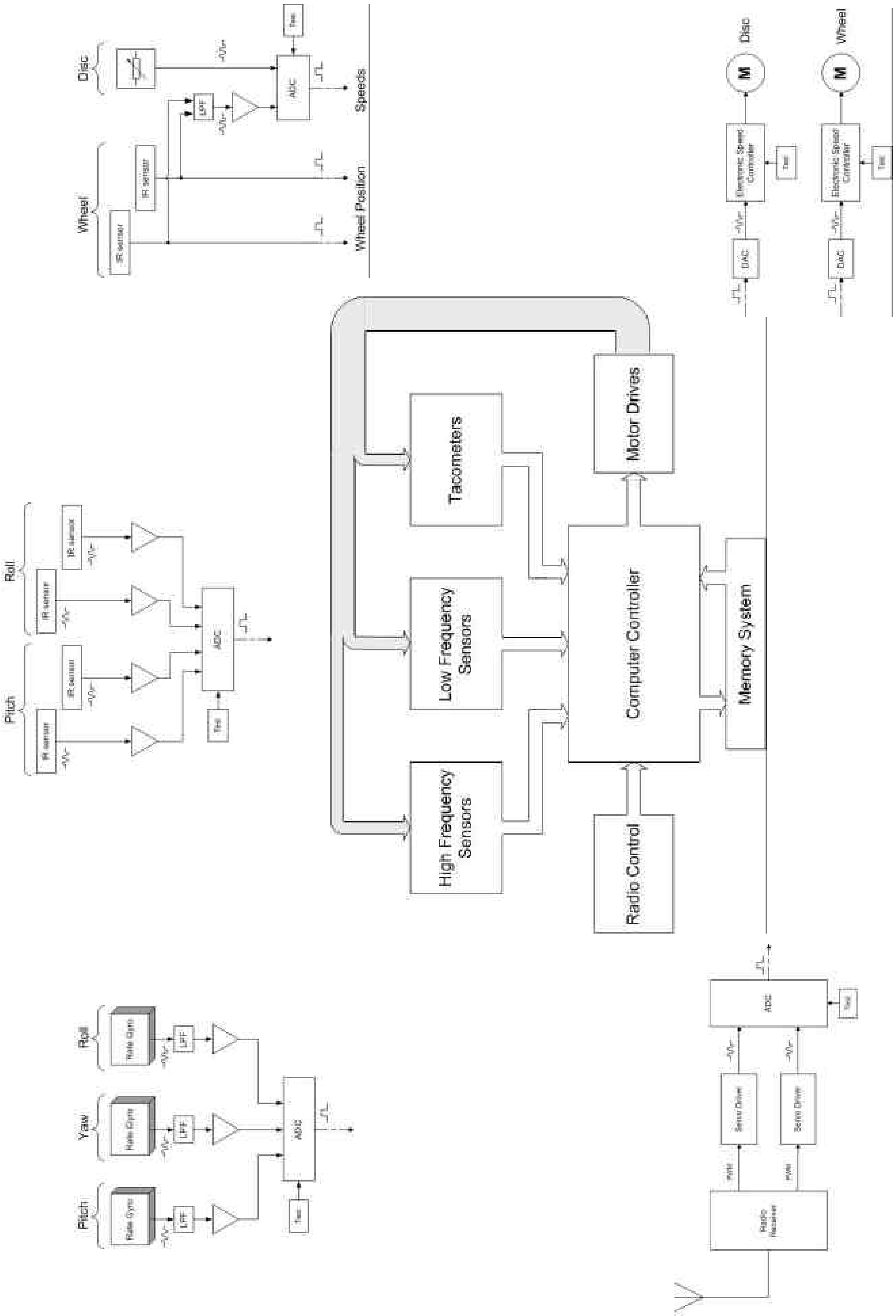


Figure 6: A promotional graphic from National Instruments indicating the use of CompactRIO.

Figure 7 shows the advantages and disadvantages of the system, determined during research into its feasibility. This solution means that no electronic circuits will need to be designed and built (except, possibly, for the power supply) and will allow more focus on the modelling and development of control algorithms. This solution brings the current status of the project towards the end of 'Phase 2', as shown in Figure 1.

Advantages	**Disadvantages & Possible Resolutions**
▪ Direction connection to sensors & actuators (ADC, DAC, isolation built-in) ▪ 200MHz processor & FPGA with built-in data transfer & logging facilities ▪ Communication to networked host computer (Ethernet, email, web hosting, ftp) ▪ Cross-platform control using web-server interface ▪ FPGA has built-in PID control functions and linear interpolation etc ▪ Multi-loop PIDs on FPGA at up to 100kS/s analogue and 1MS/s digital ▪ Case designed for harsh conditions and for small places ▪ Windows-based LabView tools; 'real-time' development ▪ On-board PDA interface / remote control web module	▪ Cost is very high relative to 'separates' solution : donated by National Instruments. ▪ Still requires speed controllers for motors (>1A) : purchase and use analogue output ▪ Ethernet for data-logging might need an umbilical? : WiFi support, PDA interface, text file logging on-board ▪ 64MB storage limit : 512MB version? Simplify data to be logged ▪ Power supply as yet undetermined : consult formal specs ▪ FPGA loses data at switch-off : installing to flash for loading onto FPGA at power-up

Figure 7: Table of advantages and disadvantages of the Compact RIO solution. After this analysis, this solution was chosen for the Robotic Unicycle.


Pitch
Yaw
Roll
Rate Gyro
LPF
ADC
Wheel
Disc
IR sensor
Speeds
Wheel Position
High Frequency Sensors
Low Frequency Sensors
Tacometers
Motor Drives
Computer Controller
Memory System
Radio Control
Electronic Speed Controller
DAC
M
Servo Driver
PWM
Radio Receiver