The Slot Car Stig: Performance and Consistency of a Slot Car Driven by a Heuristic Algorithm in an Embedded Microcontroller

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Abstract: We present theory and measured performance of an autonomous slot car driven by a heuristic algorithm on a typical track. The hardware consists of a PIC 8-bit single-chip microcontroller with various sensors driving a standard permanent-magnet (PM) brushed dc (BDC) motor in a mechanically-standard Scalextric platform. We present some interesting results concerning the relative difficulty of apparently-balanced lanes on a track. The car achieves optimum lap times with high consistency. Measured performance agrees with theoretical expectation. The consistency of performance allows the impact of experimental changes to be reliably assessed.

1   Introduction

Slot cars are popular all over the world. One might think that because one does not have to steer a slot car they do not represent a test of skill. However this is not true, as evidenced by many national championships, student competitions [1], many popular accounts of races, and a selection of electronic designs centred around the sport [2], [3], [4]. Recently digitally controlled versions that can change lanes have appeared. There are at least three manufacturers of such systems [5], [6], [7].

The authors wanted to find out whether a simple 8-bit microcontroller could drive a slot car better than a person, and if that would allow them to use slot cars to test real automotive innovations. This manuscript reports the outcome of that study.

2   Track Theory

Most slot car enthusiasts realise that a track needs to be carefully designed in order not to give an advantage to a driver in one particular lane. For example, a simple oval circuit gives a considerable advantage to the driver in the inside lane. Consider the track diagram shown in figure 1. At first glance one might expect this to represent a fair layout because there are an equal number of left and right hand turns of the same radii presented to the driver in each lane. This does not prove to be the case.

Let us assume that there is an optimum speed at which a standard car will traverse any given corner. It is possible to construct a diagram, once the optimum corner speeds are known, such as that in figure 2. This figure shows the maximum possible speed as a function of distance around the track. The square waveform assumes infinite acceleration and deceleration, the more "triangular" waveform accounts for finite acceleration and deceleration. The heuristic algorithm programmed into the car delivers the thrust required to approach the triangular trajectory as closely as possible.
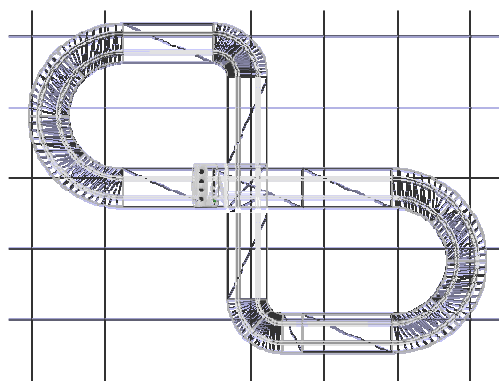

Figure 1 Scale drawing of an example slot car layout with equal left and right turns in each lane.

Figure 3 differs from figure 2 only in the lane of the track. The interesting observation is that mathematically we predict that a car travelling at optimum achievable speed will traverse one lane more quickly than the other. It is not immediately obvious but this arises because of the order in which each section of track is presented to the driver in each lane is different. Will our robot car perceive this small difference?
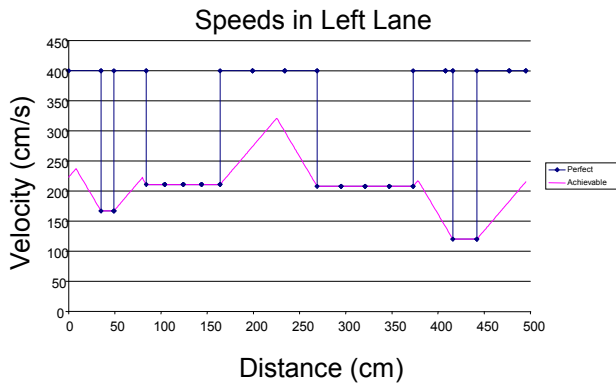
Figure 2 Plot of ideal (joined dots) and achievable (light continuous lines) velocity of a car as a function of distance around the left lane of the track shown in figure 1.
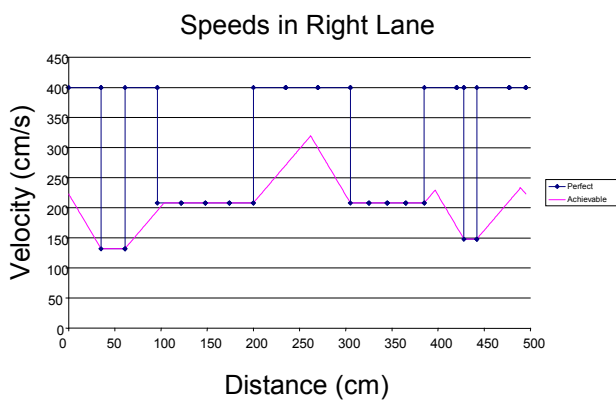

Figure 3 Plot of ideal and achievable velocity of a car as a function of distance around the *right* lane of the track shown in figure 1.

3　Vehicle Parameters

In order to program the car we need to measure optimum cornering speeds, maximum acceleration and braking, etc. These are parameters of the vehicle and track system. The parameter measurement methods are described in this section. The values are stored in non-volatile memory in the microcontroller. Eventually these parameters can be fine-tuned by the microcontroller, as a driver would tune his driving to suit his vehicle and a particular track.

Loops of identical curves, such as the example shown in figure 4, were used to determine the optimum corner speed for each radius. The car was driven around each loop at increasing thrust and the speed measured. As expected there was an optimum speed, above which the car lost traction and increased power resulted in reduced speed. These speeds were recorded. The results for the prototype car's maximum speeds are given in Table 1.

Video analysis of the car moving along a straight test track for varied levels of thrust allowed determination of the maximum acceleration and deceleration that could be achieved. Figure 5 plots the car's speed as a function of time, and also shows a linear fit to the measured data. Analysis of the data for the various thrust levels gave the optimum values.
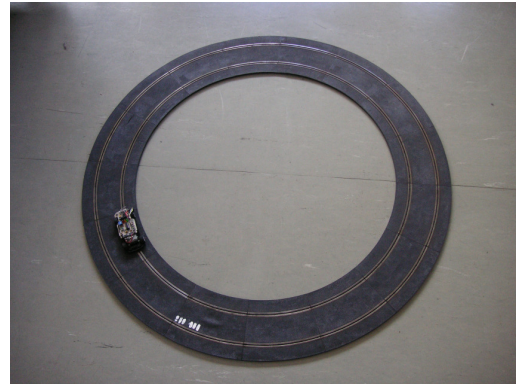

Figure 4 Example set up for measuring optimum cornering speed on a particular track section.
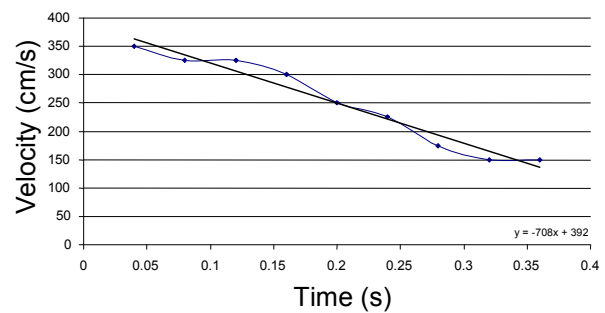

Figure 5 Optimum deceleration performance measured on the prototype car through frame-by-frame analysis of video recording, and straight line fit to the measured data.

Track Pieces and Lengths	Velocity cm/s
Straight section about 70 cm long	400
Straight section about 35 cm long	400
Straight section about 18 cm long	400
Straight section about 8 cm long	400
The Starting Grid, about 35 cm long	400
Half Std curve, turning left, LH lane	211
Half Std curve, turning right, RH lane	208
Half Std curve, turning left, RH lane	208
Half Std curve, turning right, LH lane	186
Hairpin curve, turning left, LH lane	167
Hairpin curve, turning right, RH lane	148
Hairpin curve, turning left, RH lane	132
Hairpin curve, turning right, LH lane	120
Std curve, turning left, LH lane	211
Std curve, turning right, RH lane	208
Std curve, turning left, RH lane	208
Std curve, turning right, LH lane	186
Outside curve, turning left, LH lane	250
Outside curve, turning right, RH lane	219
Outside curve, turning left, RH lane	256
Outside curve, turning right, LH lane	219

Table 1: The maximum velocity measured for each track piece.

4　Hardware

Figure 6 shows a photograph of the prototype slot car. Figure 7 shows the circuit diagram.

We built a barcode reader using an opto-sensor IC. We defined a custom barcode encoding of which an example appears in figure 8. Each barcode has a stop bit and a start bit and 5 data bits in between. The known spacing from start to stop bit allowed the car to verify its velocity as it passed each barcode. The 5 bits encoded the length, radius, and handedness of each track section by means of a lookup table in electrically-erasable non-volatile RAM. The motor was driven with a PWM pulse train. The electronics were arranged so the motor saw a low impedance in both the mark and space parts of the waveform. This was accomplished using a half bridge constructed with MOSFETs.

The track has power constantly applied. When first put on the track, the car drives slowly around until it has memorised and verified the sequence of tracks. Once memorised successfully, it puts the track sequence into non-volatile memory, proceeds to the starting straight and halts. When the photo-sensor detects the flash of a flash gun the car starts racing.

The intention was to have a learning mode, activated by the press of a button rather than the flash of light. In this mode the car will gradually increase speed on each individual track section, one at a time. When the optimum speed on each section of track is identified, the working parameters in memory are updated. This will constitute an artificially intelligent tuning process. Unfortunately time did not permit us to get to this part of the project.
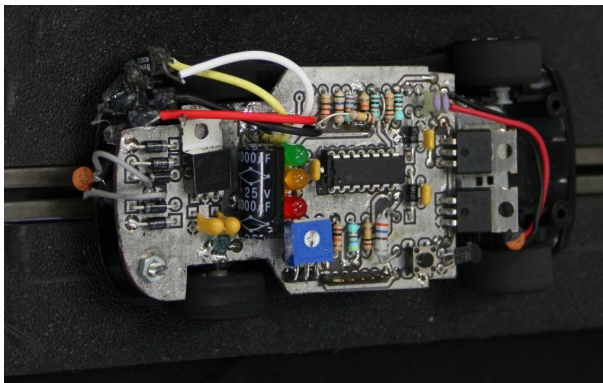

Figure 6 Photograph of the prototype slot car showing the printed circuit board. The barcode scanner is situated adjacent to the right-front wheel. A second photo sensor looks upward. The microprocessor is the 14-pin IC near the center. There is an ICSP connector for programming.
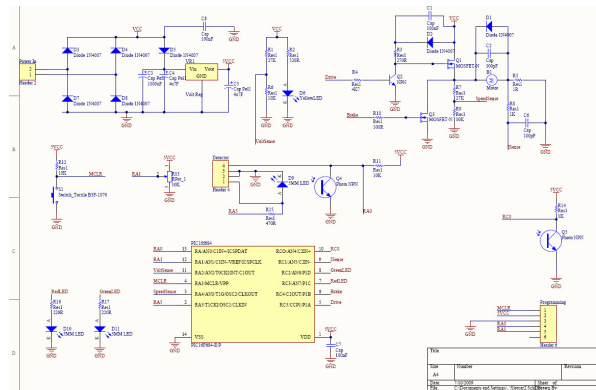

Figure 7 Complete circuit diagram of the car based around a microchip PIC16F684. Apart from a power supply regulator there are no other ICs in the entire design.
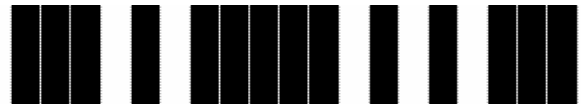

Figure 8 Example of a track identifing barcode. This code shows 10011 with start and stop bits eqaul to 1 giving a complete sequence of 1100111. Ones are white, and are always spaced apart by a black bar, so the 5 white sections in the diagram correspond to the 5 ones in the sequence 1100111. A black region appears before the start and following the stop bit. All codes are equally long, allowing a passing car to simultaneously confirm its speed.

5   Results

Figure 9 shows a cumulative frequency chart as a function of lap time measured on the track of figure 1 in left and right hand lanes for both the prototype car and a skilled volunteer known to the authors. It is immediately clear from the data in the figure that the car is faster than the most skilled human available to us. This did not surprise us.

The next observation is that the car was much more consistent in its performance than any person we tested. This serves to build our confidence that the robot slot car platform will be able to resolve the impact of any small experimental change. Indeed we were reliably able to check that tyres were properly "run in" or sense if they were worn out, or if pickups or track joints were not in order. To a user watching lap times, it feels as if you have a superhuman benchmarking everything, much like "The Stig" of Top Gear fame. Hence the title of this manuscript.

The car could readily distinguish the difference between the left and right lanes of our test track, identifying one as "easier", precisely as we had predicted. One lane recorded a track time of 3.0 s and the other 3.1 s, with a standard deviation in each case of around 0.05 seconds. This did (pleasantly) surprise us.
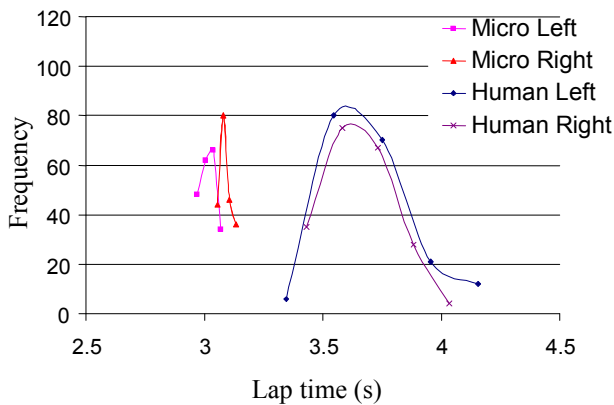
Figure 9: Plot of the frequency of lap times achieved by car and expert on left and right lanes of the test track. The consistency of the slot car compared with a skilled human clearly reveals the difference between the lanes.

4 CONCLUSIONS

When controlled electronically a slot car can perform very consistently. Heuristic driving algorithms that are readily programmed into truly low-cost, US$1, micro-controllers can deliver performance better than a practiced human. The platform allows small design innovations to be assessed with great sensitivity because of the high consistency and optimal performance. The prototype could quantify the relative difficulty of lanes in a track that might otherwise have been considered equal and balanced.

The application of scientific rigour and microcontroller precision to slot car racing has the potential to teach many lessons. We do not think it unreasonable to use the slot car model to test principles and ideas for use with real cars.

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Steven Kane expects to graduate at the end of 2009 with a Bachelor's degree in Engineering from The University of Waikato.

In 2008 he worked on a project for Novel Ways where he used electronics built into a sign to capture people's attention. He is now working in R&D at Gallaghers, researching ways to improve the electric fence. His interests include mechatronics, power electronics and computer aided engineering in finite element analyses.

Jonathan Scott (S'82-M'97-SM'98) was born in Brisbane, Australia in 1956. He received the B.Sc., B.E., M.Eng.Sc., and Ph.D. degrees from The University of Sydney, Sydney, Australia, in 1977, 1979, 1983 and 1997 respectively.

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