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Student's Contest: Self-Driven Slot Car Racing

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***Abstract*—A recently announced university student's contest is based on a well-known entertainment – slot car racing. In contrary to the classical racing, here, the challenge is to build a car which can drive on an unknown track without any human interface and achieve the best possible time. This document describes the technical, algorithmic and educational aspects of a self-driven slot car development.**

I. Introduction

THE proposal of the self-driven slot car contest was motivated by the idea to bring the university students into a development of a real-time software out of an isolated computer or laboratory environment. They would see the results of their work in real and could compare it with others on the contest. The contest subject is attractive. Probably every student knows and used to enjoy the slot car racing. Most of them think they know how to drive the car the best way.

It might look easy to drive a car which is guided and the only quantity to be controlled is the car speed. But it is not so. The development deals with a real-world compact standalone system, driven by a real-time software and using some kind of intelligence.

II. Self-Driven Slot Car Principles

The development of the self-driven slot car requires a system engineering approach. The car mechanics, electrical hardware and the driving software need to fit together. The slot car mechanics is mostly fixed and done. For the electrical hardware a reference platform exists. The emphasis is taken to the software – the self-driving algorithms.

The key thing of a winning strategy is to learn the unknown track during the first lap and use the knowledge to achieve a maximum speed in the following laps. It might not be so easy to fully map the track during a single lap only. An adaptive process of getting better precision of the track parameters might be used during the whole run, enabling to get closer and closer to the optimum drive.

Before a self-driving algorithm can be implemented, the slot car electrical hardware needs to be built. The algorithm can run on an appropriate microcontroller, which has sensors connected to its inputs and a driver of the slot car DC motor connected to its outputs.

Regarding the sensors, the most suitable sensor for mapping the circuit is an accelerometer. There are easily accessible micro-electro-mechanical accelerometers in a small package, of a low weight and a low consumption. There is no rule which would restrict to mount for example a camera on the slot car, but one always needs to keep in mind its weight and processing demands. The slot car needs to race with all its equipment on.

Regarding the slot car DC motor drive, an integrated H-bridge or half-bridge power circuit is the easiest solution. These circuits usually have an integrated over-current protection and require just one pulse-width modulated signal to control the applied motor voltage.

In order to ease the student's development and let them focus on the slot car software, a reference hardware platform is available for reuse or as a starting point. This platform includes a choice of an 8-bit or a 32-bit microcontroller, a 3-axis accelerometer and a monolithic H-bridge.

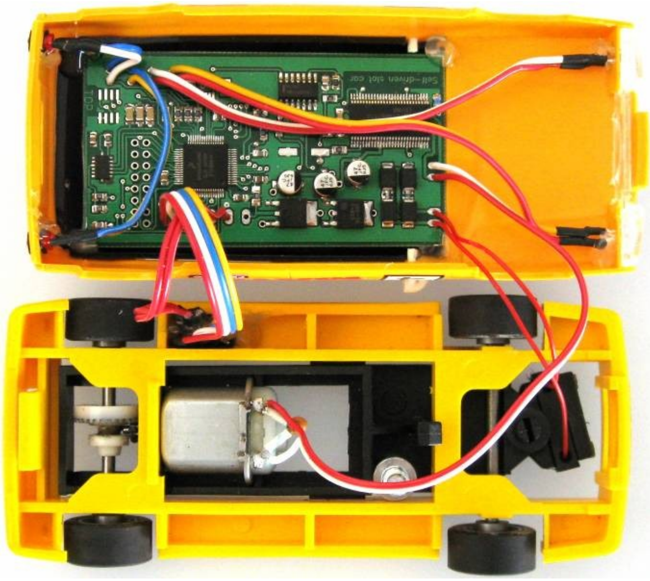

Fig. 1 The reference hardware platform built into a standard slot car

III. Contest Rules

There are three sets of rules. Rules of racing make the race clear in terms of the number of laps, measurement of time, start procedure, etc. These rules are strictly defined, so that everybody knows how his product will be measured. On the other hand, the rules for the track properties and car properties are let as free as possible. There is a set of rules unifying the slot car and track mechanical aspects, but the student's have their hands free to invent and implement various slot car improvements.

A. Rules of Racing

Each contestant races separately against time. The slot car is placed on the track about 30cm prior to the lap counter. Then, the track is powered on. On the first pass through the lap counter the time measurement is started. The race is for a specified number of laps (e.g. 10) and the total time is measured. There are two race rounds and the sum of both race times determines the final results. The slot cars are placed to the right line of the track for the first round and to the left line for the second round.

The starting order is random for the first round. For the second round, the start order is based on the first round results. The contestant with the best time in the first round starts as the last one in the second round.

B. Track Properties

The principal rule is that the race track is unknown to the contestants until just before the race, so that they can't adjust their slot cars for specific track parameters. Only the following track properties are specified:

- Track pieces producer
- Track length range (e.g. min. 10m, max 16m)
- Set of pieces the track can consist of
- Allowance of barriers
- Allowance of grade-separated junctions and altitude differences

The track properties are planned to progress year by year. For example the set of track pieces is limited to straights and curves at the beginning. Later, the set will be expanded by lane changes and crossovers. These pieces, as well as the barriers and altitude differences, may require special algorithms or even hardware improvements to detect them correctly, but also brings benefits if correctly handled.

C. Slot Car Properties

The slot cars are powered from the track. The track voltage is fixed to 12V DC. No communication between the slot car and a remote controller is allowed. The only exception is a one-way car monitoring. There might be up to one switch on the car, allowing choosing between two modes of operation. The car weight is not limited. The car size is limited such a way that the car must pass through a tunnel of defined inner height and width. The slot car chassis and guide blade must be standard. Traction magnets are not allowed.

IV. Discussion About The Slot Car Intelligence

The following discussion concentrates on several important aspects which need to be very well examined during the intelligent slot car development. The goal is not to get to a conclusion or solution. That is the contestant's job. The object it to show what kind of doubts and real-world issues the developers need to go deeply into.

A. Track Mapping Algorithm

The track mapping algorithm is mainly based on the accelerometer measurement results. Theoretically, the integration of an instantaneous acceleration determines the actual speed, and integration of a speed results in a position. This way the track shape could be mapped. Practically, the car vibrations, sensor output noise, or a small DC error on the accelerometer output overpowers the useful signal after some time of the double integration. Hence, a reasonable approach is to remember the track as a time sequence of centrifugal accelerations, which is measured at a slow speed of the first lap, and which can be converted to a high speed driving scheme for the additional laps.

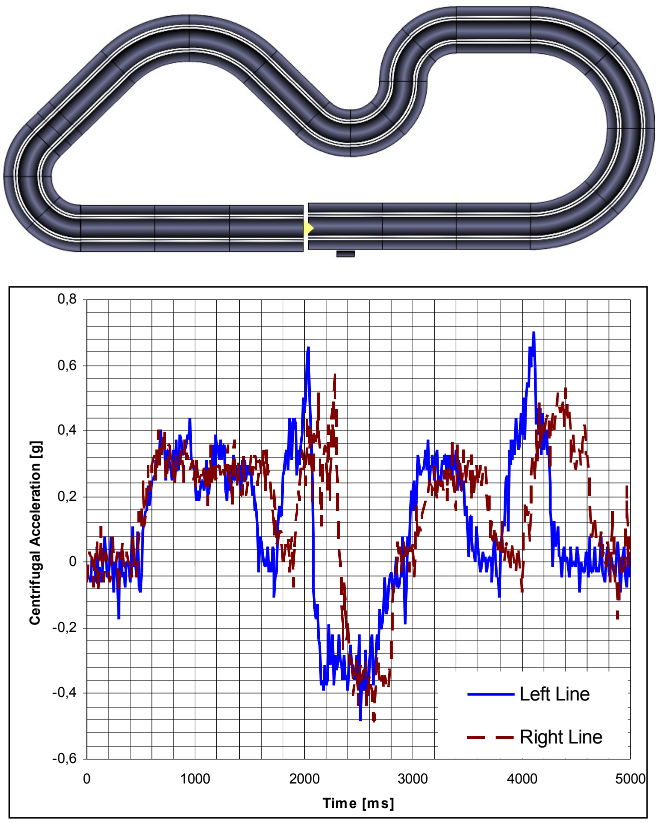

Fig. 2 A track and corresponding centrifugal accelerations measured by the slot car accelerometer

The most critical point is to recognize where the first lap ends and the second lap begins. After passing the minimal track length, the later measured part of the acceleration sequence can be compared (correlated) with the beginning part of the sequence. Once a match is found, the centrifugal acceleration sequence of the whole track is known, centrifugal forces can be predicted and the slot car can speed up.

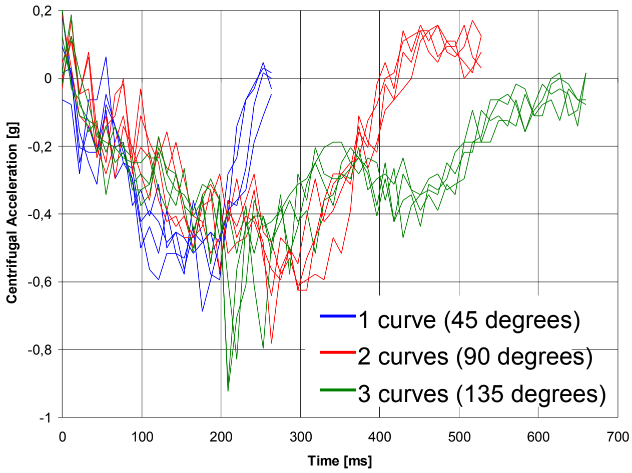

Fig. 3 Comparison of centrifugal acceleration courses measured in the smallest diameter curve of 3 different lengths (4 times each)

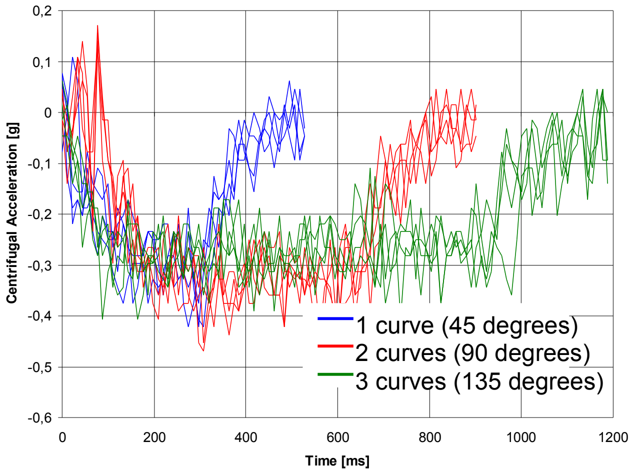

Fig. 4 Comparison of centrifugal acceleration courses measured in the biggest diameter curve of 3 different lengths (4 times each)

The described algorithm does not use any knowledgebase. With a knowledge base, the self-driving slot cars can work as a small expert system. The track property rules define a set of applicable track pieces. With the knowledge of each piece acceleration sequence, the measured sequence can be mapped to a sequence of the applicable pieces. This makes the measured acceleration sequence more reliable. Moreover, the track shape can be continuously compounded piece by piece into an XY plane. The point where the track closes corresponds to the moment when the car starts to drive the second lap. This way it can be found much sooner.

The knowledgebase may also include detailed drive schemes for various sequences of track pieces. For example, a left curve can be driven slightly faster if it is followed by a right curve, compared to if it is followed by a straight. Small differences like this one can make the big difference between the winner and the others.

Fig. 5 Set of basic track pieces: straights and curves

An intelligent slot car might use track map information obtained during the first race round also for the second round, when the car goes in the other line. The lines are never similar, but a lot of important information of the right line can be transferred to the left line.

B. Line Change and Crossover

The line change and crossover track pieces has interesting features. The most significant is the power supply gap. The slot car hardware needs to handle this in order to protect the microcontroller from a reset. On the other hand, the gap can be easily detected. It can serve as very reliable position information. There is always an even number of line changes within the track, usually two. It can be hardly confused with the crossover, because in case of the crossover there are two gaps shortly one after another. That is, again, a very reliable track mapping position feature.

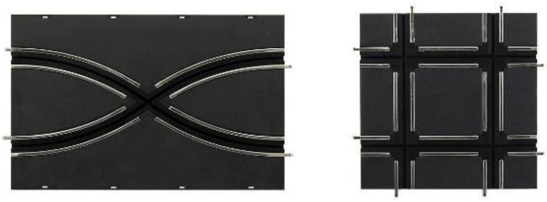

Fig. 6 Line change and crossover track pieces

C. Barriers

The barriers might be not easy to detect with just the accelerometer. If reliably detected, the driving speed of the curve can be significantly faster.

D. Altitude Differences and Grade-Separated Junctions

The track altitude differences, if allowed, bring the self-driving car several difficulties. The track mapping algorithm needs to be extended from mapping on an XY plane into mapping to an XYZ space. Also, on a flat track, the slot car speed is reasonably proportional to the applied motor voltage. This is not true on a track with altitude differences.

The car can map the altitude changes using the acceleration and tilt measurement using the Z-axis.

E. Slot Car Hardware Improvements

The discussion above resulted into several hardware improvements required by some advanced algorithms.

The detector of a power supply gap can be a simple resistor divider and a low pass filter connected between the power input and a processor input pin. Note, that there are many short power supply losses and noise spikes caused by the movement of the power source braids and by their sparking, which should be filtered out preventing their detection.

A position sensor mounted on the DC motor shaft or an axle may bring significant advantages. The slot car speed can be measured and controller by a closed loop drive system. The information about the car position on the track, especially on a long straight track part, can be precisely calculated enabling to slow down as late as possible before the next curve. But even here are some limitations. Once the car goes into a skid, the tire speed is not equal to the car speed any more.

Many other hardware improvements could be identified. Addition of other sensors enables to process other quantities, but also requires handling the information fusion. The slot car weight and complexness might result in worse controllability and less robustness. It's important to always question these aspects of hardware additions. On the other hand, the software changes are easily testable and there is a wide space open for the software improvements, for giving more and more intelligence to the self-driven slot car.

V. Conclusion

The new contest should attract university student's attention by the subject – slot car racing. This is a well-known and favorite entertainment all around the world. When the contestants start to work on the development of a self-driving slot car, with a motivation to win the contest, they discover wide possibilities how to improve the car intelligence and performance. On a deeper view, this brings them to handling real world issues in real-time software.

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