Modeling System of “Slide In” Energy Transfer Between Road and Vehicle

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***Abstract*—As fossil based fuels are ever more proving to be an unsustainable energy-source, it is of critical importance to find a new way to deliver power to the worlds vehicles in order to anticipate an ever-growing population and sustain economic growth. The task is complicated but very achievable from a technological point of view. It is however greatly overshadowed in complexity when it comes to educate about new technologies and making it seem accessible and plausible to members of the population who are not inclined to embrace radical changes.**

This thesis presents a new concept of delivering electric energy to road vehicles known as “Slide In” method. The principle of the concept is that direct delivery of energy to vehicles should occur via electrically powered slots in the road.

In order to educate people about this new idea a scaled model representing such a system has been built.

***Index Terms*—Slide In, Electrical energy transfer, hybrid vehicles.**

I. INTRODUCTION

GIVEN the lack of knowledge in the general public about the “Slide In” concept; this project is intended to make a demonstration system of the mentioned technology, with all the basic functionalities of a full scale implementation, such that it can be used to facilitate peoples understanding of this concept.

The full project was divided in three subsystems: track, vehicles and supervisory PC software, which interact with each other according to the diagram shown in Fig.1. The supervisory PC software communicates via serial RS-232 protocol with the Track and via Bluetooth with the vehicles. Also the Track can supply electrical power to the vehicles, and each section emits a unique IR (infrared) signal, which is received by the vehicles in order to identify their position along the track.

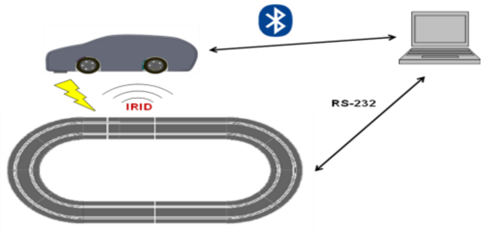

Fig. 1. Subsystems Interaction Diagram

II. TRACK MECHANICS

A. Description

The track system had to represent several features of Slide In concept on the road in an easy-understanding way. The several routes that involved the track needed to embody a concept of urban and rural paths surrounded by a main highway. The firsts consisted in non-slots paths without implementation of Slide In technology. Meanwhile, the highway had electrified slots that were able to supply power to the vehicles through the technology in demonstration. This last property emerged due to the fact that the main target of Slide In is the inter-city infrastructures of automotive transport, which cover the largest trip distances and hence most of the energy demands.

The track was constructed from Scalextric and own-built pieces in a main table of 3[m] x 4.3[m], which was also divided in six different tables of 1[m] x 2.15[m]. Besides, each sub-table had independent wiring; all of them with specific track sections and connected each other. Fig. 2 shows the definitive track model.

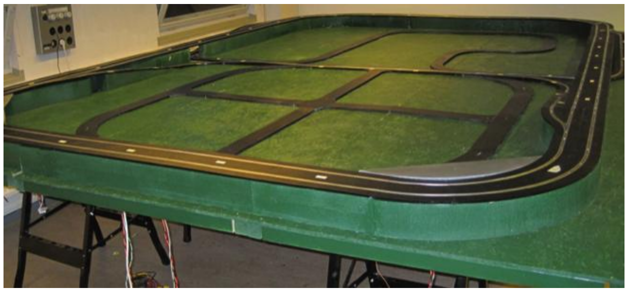

Fig. 2. Definitive Track System

B. Holder Structure

On the other hand, it was mandatory to design a holder structure for the track that was mainly planned and developed by the Engineer Getachew Darge from IEA Department. It consists in eight adjustable workbenches that were distributed and set in order to support the four (4) main wooden girders, which function is to hold the six independent track sub-tables.

C. Sections Classification

As mentioned before in the track description, two kind of paths were implemented. Therefore, the track sections were classified in two main types according to functionality reasons.

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There are sections capable of supplying power to the vehicles from the slot when it is demanded, called Track Power Sections; while some sections are unable to supply power, known as Single Track Sections; these sections can be with slot or without it.

III. TRACK HARDWARE

A. *Description*

The structure described in the Track Mechanics required the application of a complementary electronic system that would be in charge of controlling the necessary processes in order to perform Slide In technology. The development of this track electronic system consisted in the design and implementation of four main elements: the electric power supply, a master board, slave boards and a communication protocol.

Every four sections of the track were directly linked to a specific electronic board called Slave unit, which was is in charge of controlling and monitoring the operation of the corresponded sections. The processes that each slave unit performs depend on determined messages delivered from a PC. However, the communication bridge PC – slaves is not direct; a unique board was implemented know as Master unit, which has the roll of message buffer between the PC and the slave units i.e. it manages the communication PC - slaves. On the other hand, the implemented communication structure was based on the communication protocol I2C due to the simplicity of its hardware requirements.

The system electronic circuits were supplied by two main DC voltage sources of 14VDC and 3.3VDC with common ground. Finally, the scheme of the track's electronic system is illustrated in Fig. 3.

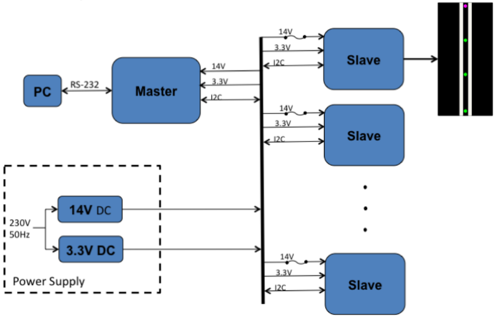

Fig. 3. Block diagram of the Track Electronic System.

B. *Master Board*

This unique board was based on the microcontroller unit of 8 bits Atmel ATmega88, which is its core of operation. The board has a MAX3232 transceiver that converts the voltage levels from TTL to RS232 and vice versa in order to handle the communication PC – MCU via serial.

Most of the messages from and to the PC are related to status or actions of slave units, which are all connected to a common I2C bus. For that reason, the Master Board has also the I2C module with its required resistors and the MCU is in charge of controlling the flow of the messages between the PC and the slaves.

On the other hand, some of the messages that come from the PC are not delivered to any slave unit. Instead, these particular messages are associated to a mechanism in the track that allows changing the direction of the traffic in the 3 track intersections. This mechanism was based on the original coils of the Scalextric lane switching mechanism but important modifications were made in order to achieve a suitable implementation. Therefore, the master board included a power electronic system for activating the coil lane switching mechanism.

The definitive scheme of the Master Board is illustrated in the Fig. 4.

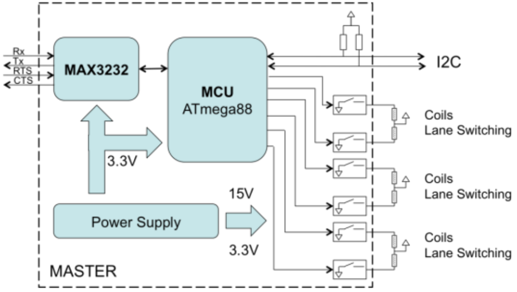

Fig. 4. Block diagram of Master Board.

C. *Slave Board*

Slave Boards are units that control all the sections that embody the track. It was implemented 30 boards that were distributed along the track according to a specific distribution.

Each slave board has the function of controlling and monitoring the operation of four determined track sections. The main processes that any slave board must perform are:

- Setting on/off the power of each section independently
- Detecting short circuits of each section
- Emitting codified infrared signals to identify each section.
- Communicate with the master unit via I2C

The Slave Boards are based on the Atmel ATTiny2313 microcontroller unit of 8 bits. The units are connected to the I2C bus, where all the data of the master – slaves communication bridge travels through. Hence, the MCU interprets the I2C messages and controls the three main mechanisms that the slave board has, according to the instruction codified into the messages. Finally, Fig. 5 presents the block diagram of the slave board.

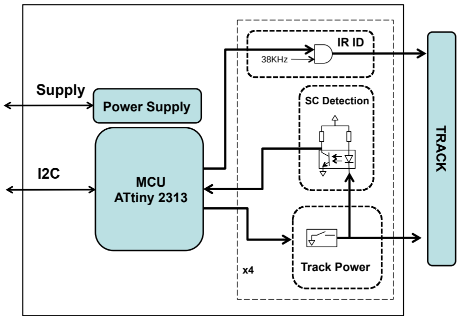

Fig. 5. Block diagram of Slave Board.

IV. TRACK SOFTWARE

A. *Communication Protocol*

As mentioned before, the Master is used in order to communicate the Slave Units with the main PC, working most of the time as a repeater; the communication from the PC to the master is via RS-232 and from the master to the slaves it's carried out through I2C protocol. The messages in the RS-232 protocol had the same structure used for I2C messages, with small modifications used only to control the communication flow.

B. *Master and Slave Software*

The microcontroller units ATmega88 and ATTiny2313 required the programming of software that includes all the tasks that the MCU must execute in order to control the main functions of each board:

- Master: Holding a communication bridge PC – slaves and controlling the six different lane switching mechanism from the track that allows setting the traffic direction.
- Slave: setting the power, detecting short circuits and emitting the infrared identification signals in each track section linked to the board.

The programming was based on C-language and performed with AVR Studio 4.

The two programs were divided in several libraries that were in charge of setting up and controlling the different resources of the MCUs. Each library has a set of functions for initialization, basic operation and in some cases, interrupts routines.

The Master program implements the USART and TWI modules to set the communication PC – Master – Slaves. Besides, it controls the mechanism of lane switching just setting output ports with a time reference based on one of the MCUs timer.

On the other hand, the slave program is mainly in charge of setting the output ports that control the power and the emission of infrared LEDs of IR ID. Moreover, the program inspects also the input ports of short circuit detection. These resources are synchronized periodically with a Timer of the MCU. Finally, the microcontroller is also configured in slave mode for I2C communication through the TWI module.

V. VEHICLE MECHANICS

In order to better convey the concept of "Slide-in" power-transfer as a viable solution to the energy problem of modern transportation, scaled vehicles that represent a large portion of today's transportation methods were developed. For this purpose, two types of vehicles were designed: a car-model and a truck-model.

The models had to accomplish the following set of goals:

- Be able to drive in a standard Scalextric-track, guided by a slot without requiring modifications to the dimensions of the slot.
- Be able to draw power from a standard Scalextric-track without modifications to the standard Scalextric rails.
- Be able to drive without external power-supply for a limited amount of time, in effect draw power from an internal battery,
- Be able to drive and steer without a guiding slot.
- Be able to autonomously control speed
- Be able to display the current state of charge of the internal battery.
- The external dimensions of the vehicle may not exceed the maximum dimension allowed for two vehicles to be able to drive simultaneously; each one guided by a separate slot of the two adjacent slots on a standard Scalextric track.
- Be easy to assemble and disassemble in order to facilitate rapid repairs in case of malfunction.

A. *Dimensioning*

Because the goal was to have both a truck- and a car-model, there had to be a visual distinction in size between the vehicles. The vehicles were dimensioned in such a way that a maximum size restriction was derived from the criteria that there should be enough clearance for two truck-models to pass each other in opposing tracks in a given curve of the track.

Moreover, the differences in length and width between cars and trucks, the convex shape of the car and the blocky two-part design of the truck were decided sufficient as visual clues to differentiate the vehicles.

B. *Connecting to road*

In order to connect the vehicles to the powered slots on the track inspiration was drawn from how Scalextric-vehicles operate a mechanism inspired on the original Scalextric-vehicles connection method was developed. They use small copper-braids that handle transferring power from the lanes despite the lane's abrasive nature and the unevenness of the track.

To follow the track's curves there is a blade, which transfers force in order to turn the vehicles along the track. The blade also rotates independently in order to align the braids with the power-conducting lanes.

However, the Scalextric-system does not offer the ability to retract the connector; a necessary ability to allow the vehicles to drive on roads without a slot. Therefore, A system was devised where this is possible. The system utilized a servo and a linkage system –see Fig. 6 - allowing the implementation of the blade and braid system developed by the authors to retract and allow slot-less driving.

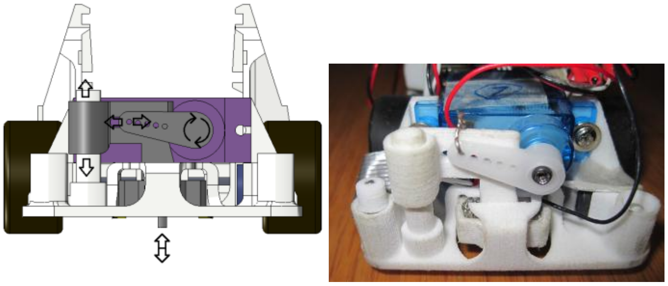

Fig. 6. Principle of operation to the left and the actual assembly of the road-connecting assembly

C. Chassis Design

The Chassis for the vehicles were designed iteratively beginning with accommodating the mechanical implementation of the drivetrain, battery and servo. These were already predetermined parts, which could not be modified. After a suitable concept was determined, the chassis was designed in parallel with the design of the vehicles electronics to optimize the space-requirements of the PCBs and the assembly process.

The iterative process was made possible by utilization of highly advanced prototyping equipment available at LTH. It uses an additive process called FDM (Fused Deposition Modeling), which creates 3D parts in ABS plastic that were structurally strong enough for this project. Because of time-constraint, the final manufacturing was done using equipment at Volvo Trucks, which uses a different process called SLS (Selective Laser Sintering)

For the design, the leading idea was to make the design as simple as possible from an assembly point-of-view and utilize as few parts as possible. This is evident in the fact that sliding them into slots or snapping them to attachments assembles most of the components. In fact, only four screws are used in the entire assembly process of the components in the car, and two of these are required because of the manufacturer's design of the servo.

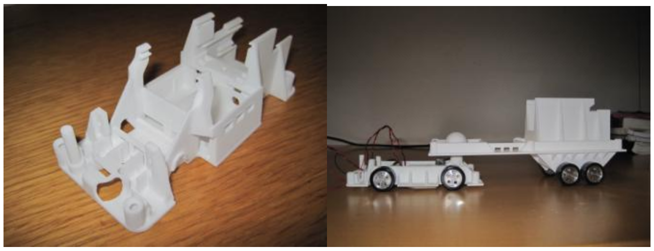

Fig. 7. The chassis of the car (lef) and the truck (right)

D. Drivetrain and steering

The drivetrain-assembly was almost completely built from off-the-shelf Scalextric parts. There is a type of bush and some axles that were custom designed.

The drivetrain is special because it also acts as the steering-mechanism for the vehicles. It is built with two electrical DC motors so that a separate amount of torque can be applied to each wheel and cause the vehicle to change its direction.

E. Aesthetic design

The vehicles were aesthetically designed in such a way that the shapes are a symbolic representation of the type of vehicle they are supposed to portray. The aesthetics are mostly embodied in the shell, which is attached to the chassis of the vehicles and cover the mechanics and electronics.

The shells also have the task of being the interface by which people pick up the vehicles, and it was considered necessary for the vehicles to portray a sense of rigidity and stability. Therefore great care was taken to reinforce the shells structurally while minimizing the weight added.

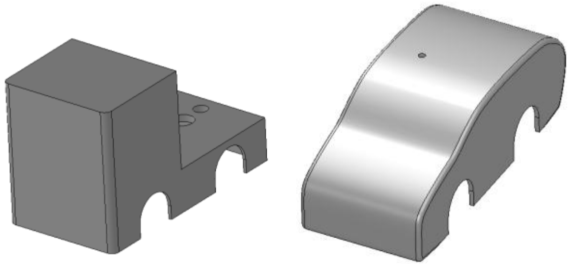

Fig. 8. The shell of the truck (left) and the car (right)

VI. VEHICLE HARDWARE

A. Description

In order to implement all the functionality required for the vehicles to work with Slide In capability, several sub systems were developed. These are: the battery, to provide the energy required by the vehicles to work offline; power boards, to control the power taken from the road to motors speed; measurement speed and coils boards and the main board, which incorporates the MCU in charge of all the processes and functions. The interconnection of all these systems is shown in the block diagram of Fig. 9.

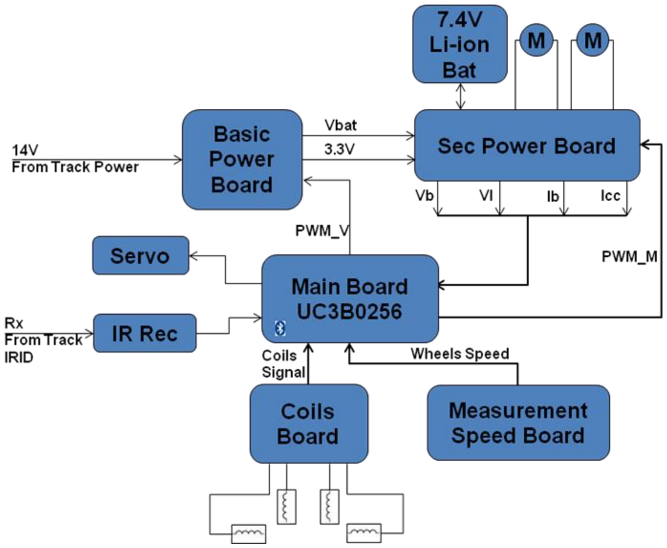

Fig. 9. Vehicles Electronics Block Diagram

B. Battery

A battery is used as the main power supply of the vehicles when there is none electrical connection to the track and it must accomplish different requirements. It has to fit inside the vehicles, be capable of sourcing 1600 [mA] for approximately half an hour and have an output voltage higher than 6 [V]. Several battery types were studied and a two cell Li-Ion battery was chosen since it accomplishes all the requirements and also has a simpler charging method compared to Ni-MH and Ni-Cd batteries.

C. Power Boards

There are two power boards in the vehicles. The first one has two DC-DC converters: a fixed one that outputs 3.3 [V] to source most of the electronic units, and another with a controllable output that converts the track voltage to the optimal level needed to charge the battery.

The second board is able to measure the track and battery voltages and the currents sunk or sourced by the battery and the other elements connected directly to the battery voltage line. It also includes a full H-bridge driver used to control the electrical motors that run the vehicles.

D. Measurement Speed Board

This board is used to generate a square wave, whose frequency is proportional to the vehicles speed. It consists of two sets of an IR LED and an IR phototransistor that are optically coupled and where the light beam between them is interrupted by a triggering wheel connected directly to a motor axis.

E. Coils Board

It conditions the signal coming from the coils used for Wire Following, so that they can be inputted to the MCU’s ADC. The conditioning consists of four stages, first an RLC resonant circuit, followed by a non-inverter amplifier, an envelope detector and another non-inverter amplifier.

F. Main Board

This is the operation core of the whole vehicles electronic system. It includes necessary hardware for a proper performance of the UC3B0256 MCU, for controlling and running the different processes that occurs in the vehicle units. The rest of the electronic boards (Main and Secondary Power Boards, Coils Board and Speed Measurement Board) are all connected to the Main Board through specific connectors. Moreover, additional hardware components are connected directly to this board: the Bluetooth module, the Servomotor, the IR Receiver and the RGB Led.

Furthermore, all the analog signals coming from the different boards of the vehicle are conditioned in low pass filters, in order to improve the data acquisition of the vehicle’s physical variables.

VII. VEHICLE SOFTWARE

A. Communication Protocol

The communication from vehicles to the PC is done via Bluetooth, but in both ends it is seen as a standard serial communication, at 115200 bauds/s, using 8 data bits, and none parity bit. There is no need to include address information in the messages, since the PC creates a COM port for each vehicle.

The most important data to be sent from the car is the current position, so that the PC can turn on and off the required sections and control the traffic to avoid crashes. Moreover, the PC needs to be able to control the car speed, and the position of the guiding mechanism (up, down or middle). For all the messages, 11 bytes are sent, including 2 start bytes, a message ID and different data and commands.

B. Controllers

Two different controllers had to be developed: one for the controllable DC-DC converter in the Main Power Board and other for the motors that run the car. In both cases, it was important to have zero steady state error and hence an Integral Part was needed; but since there was no important constrain on the setting time, a Derivative Part was not taken; therefore, a PI controller topology was decided to be implemented.

The first step to develop the controllers was to identify the systems that would be controlled; for this, the System Identification Tool from MATLAB was used. Then, the SISO Design Tool, also from MATLAB, was used design the controllers, using the automatically PID tuning.

Once the controllers were obtained, they were discretized and all the constants were converted to fixed point format, in order to be programmed in the target MCU. Also, for the motors controller, a smooth start-up algorithm was implemented to solve problems when starting from the stationary position due to static friction.

C. Battery Management

In order to charge the Li-Ion battery, the Constant Voltage Charging method is used. It consists of two steps: the first one where the charging current is limited at 1C (constant current) and the second one where battery is charged at a constant voltage of 8.4 [V].

Also, an algorithm was used to estimate the battery state of charge (SoC), it consists of modeling the battery as a voltage source, representing the open circuit voltage, in series with a resistance, were the SoC is related with the open circuit voltage. At all times, the open circuit voltage is estimated and its value is looked up in a table for the corresponding SoC.

D. Code

The MCU performs multiple tasks, including PI controllers, Pulse Width Modulation (PWM), USART communication, analog-to-digital conversions, external and time-triggered interruptions, among others. In order to control the MCU modules needed by these tasks, pre-programmed drivers from AVR were used, which include functions to both initialize and use all the peripherals functionalities.

Also, to simplify the programming and debugging process, each task was developed individually, and all of its functions and variables were included into a library with its code (.c) and header (.h) files. The integration off all the tasks is performed in the Main.c file, which also directs the program flow. In total eleven libraries were developed.

The main function integrates all the libraries and directs the program flow. It first initializes the system clock to its desired frequency and calls the initialization functions for all libraries; then it enters into an infinite loop. This loop is composed by five different code sections which execute at 400, 50, 25, 16 and 5 [Hz] and each of them is in charge of specific tasks.

VIII. PC SOFTWARE

The PC software serves multiple purposes demanded to perform the demonstration of Slide In. It must control the entire system by reading back the state of the entire track, making decisions based on the state, and issue commands to execute those decisions. It also has to serve as an easy-to-use user-interface for people that are interested in the model.

A. Language

The language used to develop the PC-software was Java. The main reason is its inherent portability across many platforms, the amount of ready-to-use libraries available and also the real-time programming capabilities of Java.

The development was done in the open-source Eclipse IDE, which compiled it using Oracle's proprietary Java JDK

B. Communications

The communications were in a physical sense done via a USB-RS232-port and a Bluetooth module. However, these serial interfaces allowed themselves to be interfaced in a unified way via a common serial communication API. This was made possible due to the fact that the RF-COMM spec of Bluetooth is viewed as a RS232 port by the operating system.

The library used to access the RS232 port of the operating system was the open-source Rxtx-library.

C. User interaction

To allow an easy interaction between users and the system, a Graphical User Interface (GUI) was developed. The most prominent feature of the GUI is a scalable image of the track that displays the currently powered sections and the position of each vehicle. On the left side the user can select a vehicle and monitor its data on the right: State of charge of the battery, vehicles speed and power consumption.

The interface was developed using OpenGL to create fast graphics. Because OpenGL is written in C-code a wrapper library had to be utilize to interface it with Java. The library used was an open-source library called Libgdx.

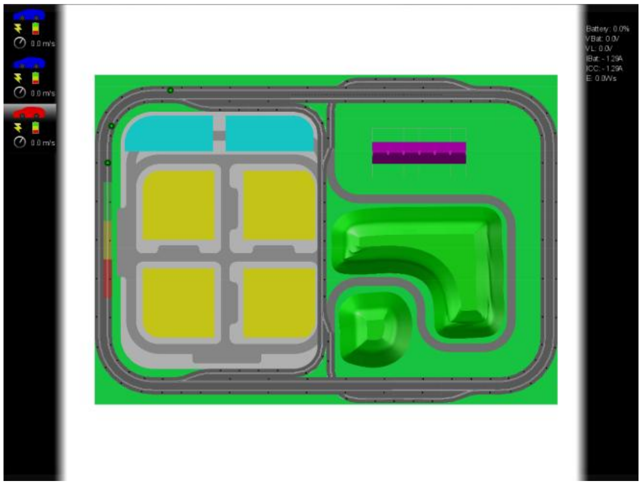

Fig. 10. Screenshot of the GUI (Graphical User Interface) for the PC-software

IX. CONCLUSIONS

This master thesis project consisted in the development of a full-scale demonstration system of Slide In technology. From original Scalextric track pieces, it was possible to design and develop a structure that involves the several features of this mentioned technology. The system development was distributed in the design and implementation of a Track, Vehicle units and PC software simultaneously.

Scalextric tracks were modified mechanically and electrically in order to build the track system with the addition of electronic devices that monitor and control all track sections.

Models representing car and trucks models were developed. All the vehicles have a set of five custom electronic boards that were designed and manufactured to achieve both functionality and space requirements in the vehicles. The mechanical properties of the moving units were adapted from original Scalextric cars parts. Every vehicle has an array of integrated systems. Examples of these are: Bluetooth communication, speed measurement, a battery that is chargeable via powered lanes on the road, infrared receiver to determine the local position, a servo mechanism in order to get in/out the road slots and sophisticated speed control.

Furthermore, PC software was developed that is in charge of coordinating the track and vehicle units' in a traffic system and also provides user interaction.

Despite of the fact that the requirements to perform a demonstration system of Slide In technology were fulfilled, difficulties arose along the course of development that impeded the desired performance of the system.

First, the simultaneous development of the vehicle mechanics and electronics obstructed to test the integrated system until the final stage was reached. Therefore, there was not enough time to improve as desired the performance of the vehicle units.

The main problem created by an uncompleted integration stage of vehicle mechanics and electronics was the performance of the speed-measurement system; which is very sensitive to noise, especially when the cars are charging and the motors are running. This issue was related to a poor implementation of the system to generate speed dependent impulses; vibrations in the motor axis affected the plastic foil disc that interrupts the light beam between infrared receiver and transmitter. The lack of time avoided the development of a more reliable system.

Second, one of the main drawbacks in the vehicles was related to following a guiding wire. Because the front wheel assembly was designed in such a way that the front wheels were locked, the rear wheels weren't able to generate enough traction in order to rotate the vehicles on the surfaces which were used to model roads. The result is that the cars are unable to reliably drive in curved roads without mechanical assistance. A new implementation where the front wheels aren't locked together or a more complex solution where the steering is obtained by angling the front wheels in a similar manner to conventional cars might solve the problem.

Finally there were issues regarding the responsiveness of the track control system, which impeded the desired performance of the track. The circuits that set the track power on or off communicate to a so-called "Master" circuit via an I2C bus. The "Master" then relays the signals to the PC via an RS232 bus. There are certain problems in the implementation of the I2C bus, which caused significant delays in communication between the PC – control software and the track.