Data Acquisition and Logging System for Electric Motorcycle Prototype

Diogo Luís
Dept. of Electrical and Computers Engineering
IST, University of Lisbon
Lisbon, Portugal
diogo.m.luis@tecnico.ulisboa.pt

***Abstract*—In automotive racing, every second counts when it comes to winning a race. If the pilot brakes too early or makes too wide of a turn, they risk being overtaken and loosing the advantage. Thus, it is of major interest to be aware of how the vehicle behaves on track. In professional automotive sports, such as Formula 1 and MotoGP, the teams resort to the use of telemetry to improve machine and rider performance. This article refers to the telemetry system developed for an electric racing motorcycle prototype, built by Portuguese students at Instituto Superior Técnico. This telemetry system is equipped with various sensors and communicates with the other sub-systems within the motorcycle, in order to collect and log as much information as possible. This piece of equipment has allowed the team at TLMoto to better understand the behavior of the prototype, advise the rider and also to troubleshoot other parts of the vehicle.**

***Index Terms*—telemetry, data acquisition, data logging, sensors, racing motorcycle**

I. Introduction

TLMOTO is a team made of students, mainly from IST, which is dedicated to projecting, building and racing electric motorcycles for international competitions around the world, like the one shown in figure 1. This team is made up of various technical and non-technical departments such as: aerodynamics and cooling, dynamics, electronics, powertrain, structures, marketing, management and sponsors. This project is developed within the scope of the electronics department, more specifically, the telemetry sub-department. Telemetry is the measurement of data from a distant object or vehicle, and, in many cases, the transmission of those measurements to a ground-station or database [1]. However, all the competitions (like MotoStudent™, Moto Engineering Italy™, etc.) prohibit the use of live telemetry data transmission, as is the case of the professional MotoGP. As stated on the official regulation documents of those competitions, the telemetry data obtained from the prototype must only be acquired during pit-stops.

This paper describes the development and functioning of the telemetry system built for the next TLMoto prototype, TLM04e. The telemetry acquisition is a very important subsystem of the prototype, as it allows the team to have an accurate description of its behaviour in tests and races, as well as to provide feedback and suggestions to the pilot. It also plays a big roll in understanding what could be altered on the current prototype or what could be improved on the next one [2].

Fig. 1. TLM03e

II. Desired Functions

This system is intended to measure, manage, store and finally transmit all the acquired data, which is then sent to an external computer to be properly processed and displayed to the pit crew. The objective is to extract the maximum of useful data to accurately characterize the prototype, while avoiding to overload the system. For this reason, not only the physical quantities to obtain must be chosen wisely, but also the system must be fast and robust so the loss of information is minimal. It should collect information about the dynamic, mechanical, electrical and thermal aspects of the motorcycle, as well as the control inputs given by the pilot, in order to observe how the prototype actually responds to commands and compare it with the expected response.

The most important items to quantify are: velocity, accelerations, RPM, suspension travel, temperatures of the motor and controller, temperatures of the battery packs, voltages of the battery packs, current from the battery, accelerator and brakes inputs and position over time so the parameters can be analysed along the track. Some other values that are obtained are, for example: phasor components of the motor current (I_d, I_q), torque, handlebar steering angle, roll and pitch angles, among others.

As per the data logging and retrieving, all the acquired values are stored during the laps in an SD card, that can be conveniently removed and plugged in to a computer. Alternatively to the removal of the SD card, the content of the telemetry may be transmitted to the computer via Bluetooth, using the Bluetooth 5.0 module included in the system's last iteration. This is done as such because, as mentioned earlier, distant communication is not allowed by the regulation and the retrieving of the data must be done only within the premises of the box.

III. Sensors and other components

Before specifying what sensors to get, it is best to figure what is already available in the prototype that can provide information about the parameters mentioned in section II.

A. Controller

One very important component for our motorcycle and any other electric vehicle is the controller [3], which is used as an interface between the accumulator and the motor. The TLM03e uses a *Sevcon Gen4 Size 6* controller to turn the 126V of direct current from the battery into three-phase AC voltage for the motor. This device is able to control and measure the motor's rotations per minute (RPM), torque and currents, as well as to keep track of the temperatures of the motor and the controller itself. All those parameters are sent to the CAN bus (Controller Area Network) that connects all the sub-systems of the Low Voltage System and then received by the telemetry module.

B. Battery Management System

The accumulator is a set of many battery cells in series and parallel configurations. The one in TLM03e is divided in five battery packs, each made of six sets of cells, and they must be constantly monitored and balanced between each other. This task is accomplished by yet another sub-system called BMS (Battery Management System)[4]. The BMS measures the voltage of every individual set of cells and the temperature in three points of every pack. The voltage and temperature values obtained by the BMS are sent to the CAN bus.

C. On-board Sensors

The position coordinates of the motorcycle along the track are collected by a GPS module. The chosen module was a *GPS 4 Click* from MikroE, which has a reasonably good accuracy and can provide an update rate of up to 10 Hz. It outputs messages in the NMEA format with information about the coordinates, UTC time and estimated velocity. We use a "mouse" antenna outside the carbon fiber fairing to avoid RF shielding.

The accelerations and rotation angles – mainly from pitch and roll – acting on the motorcycle are measured by an Inertial Measurement Unit, or IMU, based on the ICM-20948 microchip. It includes a three axis accelerometer, a three axis gyroscope and a three axis magnetometer, thus providing nine degrees of freedom.

The suspension travel is obtained with the use of two linear potentiometers, one for the front suspension and one for rear one. A linear potentiometer translates a variable resistance into a linear displacement. This solution requires constant contact between the wiper and the resistive path, which may reduce durability due to friction. An alternative would be a LVDT, however this uses AC signals, requiring more complex implementation on the circuit.

The accelerator handle includes a rotary potentiometer in order to measure the acceleration inputs from the pilot. Its terminals are directly connected to the controller as this is what will determine the mechanical power requested to the motor. The value corresponding to the accelerator knob is also sent to the telemetry system via CAN.

It is noteworthy to mention that our prototype does not have a gearbox, much like the vast majority of electric vehicles, meaning that the linear velocity can very easily be calculated from the motor RPM. This is due to the direct link between the motor shaft and the wheel sprocket, as shown in figure 2. In fact, the velocity is directly proportional to the RPM according to equation 1:

$$v[km/h] = \frac{rpm \times 2\pi \times r_{wheel}}{60} \times R_G \times \frac{3600}{1000} \quad (1)$$

where r_{wheel} is the outer radius of the tire and R_G is the gear ratio used for this conversion.

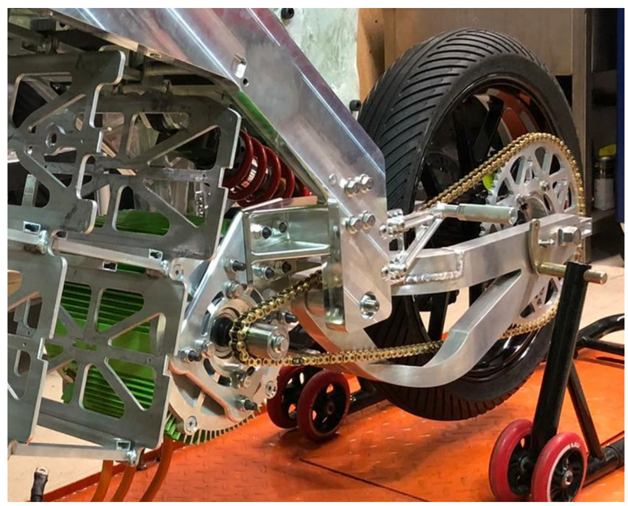

Fig. 2. Link between the motor shaft and the wheel sprocket

This method is fairly reliable and allows to get a complementary value of velocity to the GPS with no additional sensors. There is, however, some error associated with the rear wheel drifting on the track, but this appears to be residual as the prototype has considerable downforce [5], specially at high speeds.

IV. Hardware and PCB design

Figure 3 illustrates the PCB layout from the latest design of the telemetry system. The schematic and layout were made in Altium Designer, the board was manufactured at JLCPCB and it was soldered at TLMoto's workshop in IST. The figure represents only the top layer of the PCB, so some connections are not visible because they are in the bottom layer.

This board includes all sensors and components described above, all commanded by a STM32 microcontroller at the very center. The microcontroller is responsible for collecting, buffering and periodically loading the data to the SD card. It also includes a CAN transceiver and dual Ethernet port for the CAN bus and also for power.

The board operates at 3.3V and requires 5V for some devices. It may be powered through a mini-USB, while programming and debugging, but during its normal operation, it is supplied by the bus that connects the whole Low Voltage System of the motorcycle.

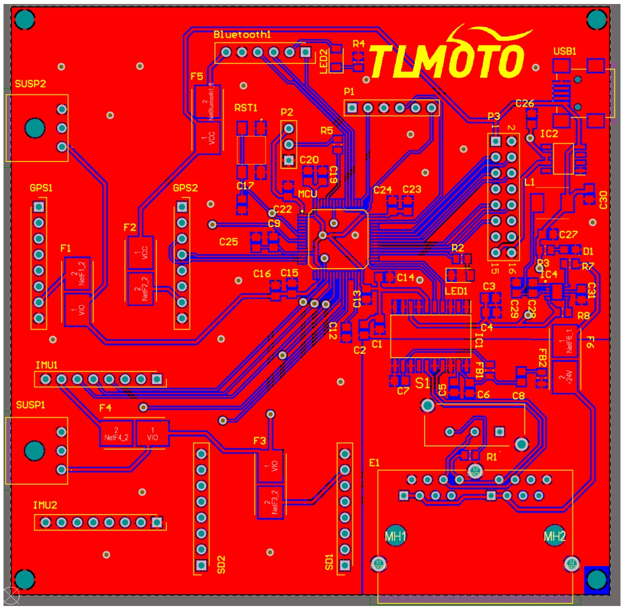

Fig. 3. Printed Circuit Board of the telemetry system

V. Handling the Data

The GPS module sends the time, coordinates and speed via UART in the format of NMEA strings. The CAN messages are arranged according to table I.

TABLE I
CAN messages sent from the controller and from the BMS

CAN ID	B1	B2	B3	B4	B5	B6	B7	B8	
11	Target I_d		Target I_q		I_f		I_q		Controller
12	U_d		U_q		Motor PWM		AC Volt.		
13	AC Curr.		Max I_q		Motor Temp.		Battery Volt.		
14	Cap. Volt.		Controller Temp.		Battery Curr.		Torque		
15	RPM				Throttle Volt.		Throttle Value		
51	Cell Voltages of Pack 1								BMS
52	Cell Voltages of Pack 2								
53	Cell Voltages of Pack 3								
54	Cell Voltages of Pack 4								
55	Cell Voltages of Pack 5								
121	Temperatures in Packs 1 and 2								
122	Temperatures in Packs 3 and 4								
123	Temperatures in Pack 5								

All the collected parameters are organized and logged into the SD card, in a CSV file (comma-separated values). This file is then loaded to a computer, which will process the data and generate the desired graphs.

VI. Results

In this section are shown a few of the many graphs generated from the data acquired while testing the TLM03e in the KIRO (Kartódromo Internacional da Região Oeste) track in Bombarral. Although the telemetry system described in this document was made for TLM04e, this motorcycle is still in development. Thus, the tests were performed with the previous prototype, since this is a modular block compatible with the rest of the system.

In figure 4, it is shown the route of the motorcycle, in the shape of the KIRO track. The color of each point represents its instantaneous velocity according to the color bar to the right. From the image it is clear that, predictably, the speed is lower on the turns and substantially increases in straight lines.

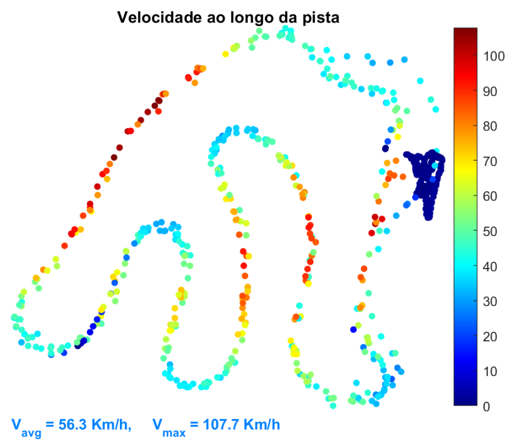

Fig. 4. Velocity along the track

Figure 5 shows the value of the throttle handle potentiometer along the track. The brightest shade of green means the throttle value is 100% and the darkest shade means that the handle is released. As can be observed, the rider accelerates more at the end of every turn. This information can be interpreted by the pit crew in order to advise the rider.

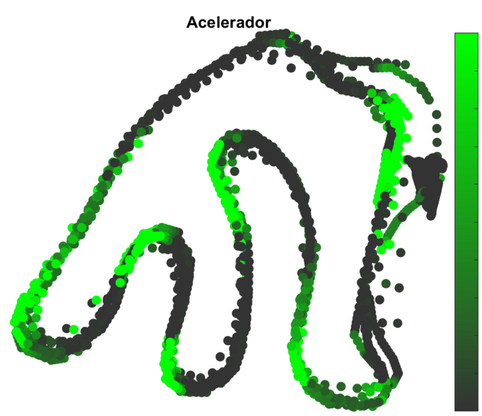

Fig. 5. Throttle along the track

Figure 6 illustrates how the motor RPM correlates with throttle percentage. When the throttle is set to a constant value, the speed rises at constant rate, when it is released the motorcycle decelerates.

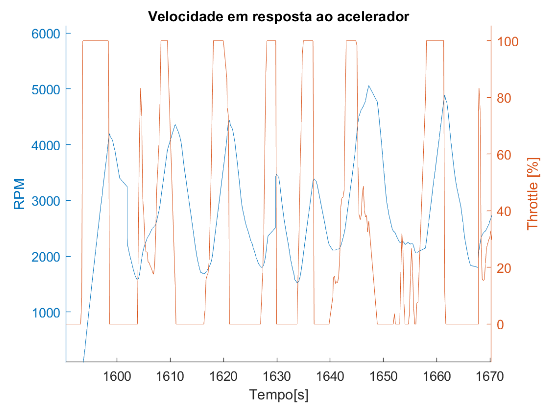

Fig. 6. Relationship between speed and throttle value

Fig. 7 describes the temperature of the motor during a two stage test, where the motorcycle runs for six laps, then stops for about 15 minutes for feedback with the pilot and then goes on for another five laps.

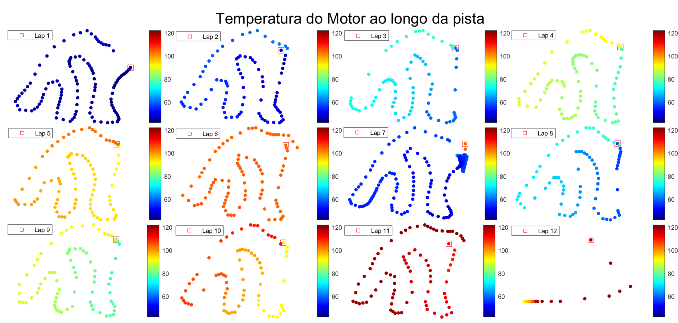

Fig. 7. Motor temperature along the track

On the first part of the test, the temperature rises gradually, eventually reaching $106°C$. Afterwards, the vehicle returns to the pit (located on the high density area on the right on the "lap 7" window), where it cools off to below $60°C$. Finally, on the second run the temperature goes up to $121°C$. Figure 8 describes the same test, plotting the temperatures of the motor and the controller over time.

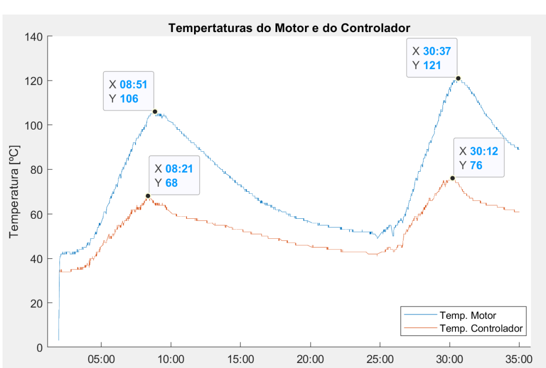

Fig. 8. Motor and controller temperatures over time

Still from the same set of data, figure 9 demonstrates how the voltage on the battery varies during the test run. The voltage starts off just below 117 V and finishes the test with 110 V. The spiky areas occur when the motorcycle is running and are caused by the current peaks on the High Voltage System.

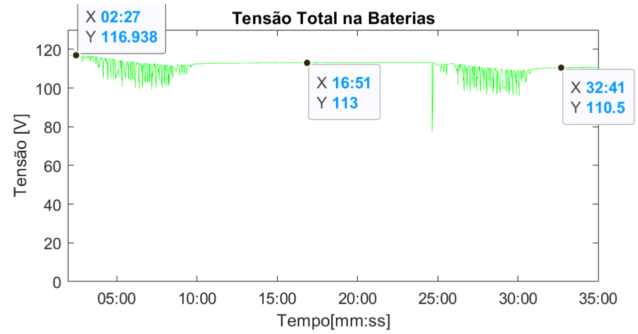

Fig. 9. Battery Voltage over time

The team was able to generate plenty of graphs just like the ones in this section, allowing to describe these and many other parameters of interest.

VII. Conclusion

The telemetry system described in this document serves its purpose of better understanding how the prototype behaves in track and how the rider handles it. It has allowed the team to improve performance, to keep track of important parameters and to display them in a visual and organized disposition. Although this equipment is still in development, it is already being implemented as a sub-system on the current and upcoming prototypes.

However, as can be observed in the results from section VI, there is some occasional data loss, especially on the GPS. We also noticed a few glitches in the values of some acquisitions due to errors in communication. These and other problems will soon be fixed. The telemetry sub-department is also working on a graphical user interface, in order to provide an convenient and intuitive manner of navigating through the desired graphs.

It is also relevant to mention the didactic value of this project. The development of this system gathers important aspects of embedded systems, both in the hardware and software components.

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