ROVIM T2D - an Autonomous Surveillance Robot for IEEE Journals

Gonçalo André, Student, Instituto Superior Técnico

***Abstract*—In the last decade, technological advancements have enabled a rise of autonomous robotic applications for military use. With the goal of exploring its potential in surveilling military facilities, the Academia Militar commissioned the development and construction of a functioning prototype of an autonomous vehicle. In this article the traction, steering and braking actuators of such vehicle are addressed. Current research focuses on commercial road vehicle applications where autonomy is the key topic, whereas small, non-professional teams often struggle with a lack of clear vision of the whole project and lax safety procedures. A quad vehicle embedded with an electric battery pack, traction, steering and braking actuators, along with a control and interface mechanism, with a design focus on flexibility and personnel safety is proposed and evaluated. Limitations of the proposed design are identified and solutions proposed.**

***Index Terms*—Electric vehicles, Vehicle safety, Magnetic sensors, Steering systems, Robot motion control, Robot programming**

I. INTRODUCTION

THE Academia Militar commissioned a functioning prototype of an electric autonomous vehicle, the Robô de Vigilncia de Instalações Militares (ROVIM), to use in military facilities surveillance. It consists of three parts: Tração, Travagem e Direção (T2D), Sensores e Navegação (SeN) and Comunicações e Posto de Controlo (CPC), that interact with each other in a layered mode, similar to the Open Systems Interconnection (OSI) model. The T2D comprises the traction, steering, and braking actuators, along with the power supply and a system control and interface.

Purely electric propulsion is mainly adequate to small electric vehicles at low speed applications [1], such as the ROVIM. The propulsion system is the main component of an electric vehicle and includes its traction controller, motor, and wheels [1]. In [2], a motor topology comparison for electric vehicles is presented. Based on its criteria, a Lynch motor type was evaluated and chosen for this application, mostly due to its compactness, and the fact that a sister project used similar motors, allowing exchange of components and ideas.

In [3], several battery technologies suited to hybrid and electric vehicles are presented, of which three families are the most suited to this application:

- Nickel Metal Hydride (NiMH), the most used technology on commercial road vehicles [3]. However, they require a battery management system;
- Lithium-ion (Li-Ion), the most energy dense type. They however are very prone to exploding if overcharged;
- Valve-Regulated Lead-Acid (VRLA), a reliable and widespread technology, with low energy density, but that are still suited to small vehicles.

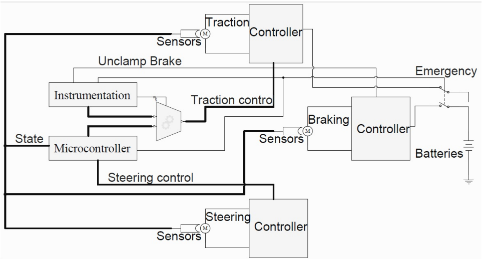


Fig. 1. Block diagram of the system. Bold connections denote signal buses.

VRLA batteries where chosen for this prototype version, mostly due to their reliability.

II. T2D COMPONENTS

The T2D subsystem has three major components (the actuators), around which are designed a security mechanism, driving features and monitoring tasks. The system's internal connections are show in a simplified diagram in Fig. 1. Each motor is driven by a specific controller and has a sensor array to capture the state of the mechanism it moves. The power connection to the traction and braking controllers is complementarily controlled by a safety mechanism which, when triggered, cuts the first and connects the second, thereby bringing the vehicle to a halt. The safety mechanism has an extensive set of triggers to enable its use in all panic situations and can be controlled both by the user and the microcontroller. The microcontroller's running program, besides providing driving features, also runs a system monitoring task that scans the sensors to detect and act on incoherent states.

Driving features are included in embedded instrumentation panels and in the control program's user interface, allowing the vehicle to be driven by a user next to it (manual mode) or by a computer program, with or without user interaction (autonomous mode).

A. Chassis of the ROVIM

A chassis from a quad motorcycle with internal combustion engine was modified for this application. The old engine and all other unnecessary parts were removed and a wide frame for two platforms was built in its place. In addition, mounting stands for the motors and the sensors were installed. The total kerb weight of the vehicle is just under $250\,\mathrm{kg}$ and its wheel radius measure $23\,\mathrm{cm}$ and $28\,\mathrm{cm}$ from and rear, respectively.

B. Embedded battery system

Clever packaging allowed the central lower part of the motorcycle to be used solely for battery placement, in an area free from most accidental interference. However, due to limitations in fabrication methods, it was not possible to fasten them to the chassis nor properly insulate their contacts.

On the lower platform, six VRLA batteries were installed in a series connection and provide a maximum of $150\,\mathrm{A}$ at $12\,\mathrm{V}$ and $72\,\mathrm{V}$ outputs and store $4.05\,\mathrm{kW\,h}$. Chargers for individual batteries and for the whole group were also acquired.

C. Traction of the ROVIM

To estimate the power needed to propel the vehicle, a worst-case scenario was designed, where the vehicle is travelling at $3.33\,\mathrm{km\,h^{-1}}$ in a sandy terrain with a $150\,\mathrm{kg}$ extra load. According to [4, p. 117], the typical rolling resistance of car tires on sand is 0.3. At such low speeds, the force resisting vehicle motion can be approximated to the rolling resistance so, from the relation between torque and power,

$$P = \omega \cdot T \tag{1}$$

where P is the power delivered by the motor, T is the torque on the wheels needed to win motion resistance and ω is the angular velocity of the wheels, which can be expressed in terms of the linear velocity by:

$$\omega = \frac{v}{r} \tag{2}$$

where v is the linear velocity of the vehicle and r is the rear wheel radius. Since the resistive torque can be approximated as the rolling resistance torque, the total torque is:

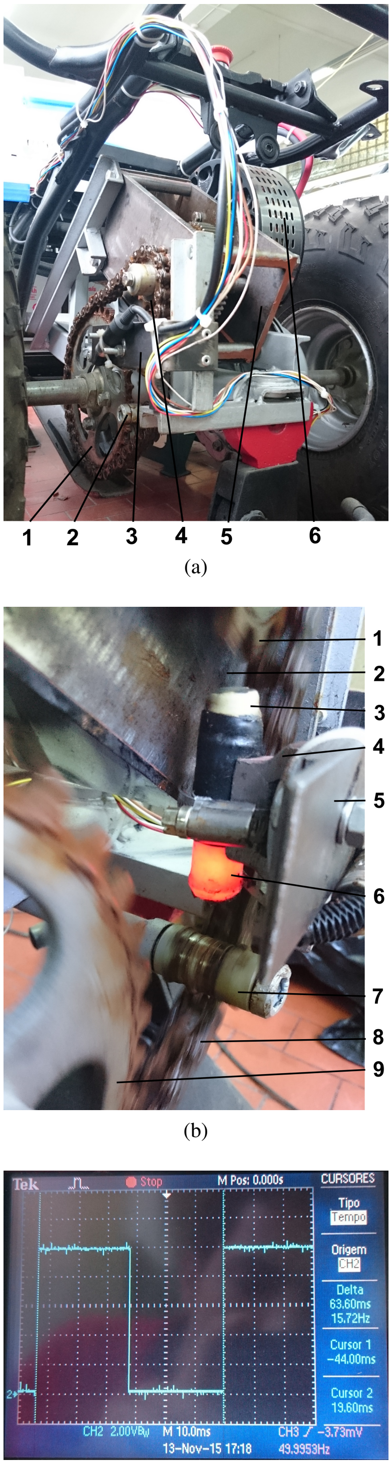
$$\begin{aligned} T &\approx T_a && (3) \\ &= m \cdot g \cdot \beta \cdot r && (4) \end{aligned}$$

where g is the gravity acceleration, ≈ 10, and β is the rolling resistance coefficient. Replacing in (1),

$$\begin{aligned} P &= v \cdot m \cdot g \cdot b && (5) \\ &= \frac{3.33}{3.6} \cdot 400 \cdot 10 \cdot 0.3 && (6) \\ &= 1.1\,\mathrm{kW} && (7) \end{aligned}$$

Despite the expected power needs, a powerful Lynch type, $16\,\mathrm{kW}$ motor was selected to propel the vehicle that could be placed above the rear fork, freeing up space for the batteries at the center and allowing the modules to be neatly separated. To connect the power to the wheels, a single ratio gearbox was designed and commissioned, allowing reuse of the original sprockets, control over component layout and enabling a higher reduction ratio than commercially available options. The set up of the traction actuator is shown in Fig. 2a, and was placed to align the rear axle and the gearbox sprockets.

A four quadrant permanent magnet Direct Current (DC) motor controller recommended by the motor manufacturer was acquired in a easy assemble kit and initially wired according to [5, p. 15] to achieve manual driving functionality and evaluate the work plan at an intermediate stage. After that, additions discussed in II-F were made to achieve autonomous driving capabilities.



(a)

(b)

(c)

Fig. 2. ROVIM traction subsystem's sensors and actuators.
a) traction actuator mount: 1 – rear axle sprocket; 2 – chain tensioner; 3 – sensor mount; 4 – reductor exit sprocket; 5 – transmission reductor; 6 – traction motor.
b) speed sensor mount: 1 – reductor exit sprocket; 2 – transmission reductor; 3 – sensor capsule; 4 – mounting adaptor; 5 – mounting structure; 6 – signal light; 7 – chain tensioner; 8 – chain; 9 – rear axle sprocket.
c) sensor readings from a $86\,\mathrm{rpm}$ mounted gear. Y axis is sensor output voltage at $2\,\mathrm{V/div}$; X axis is time at $10\,\mathrm{ms/div}$.

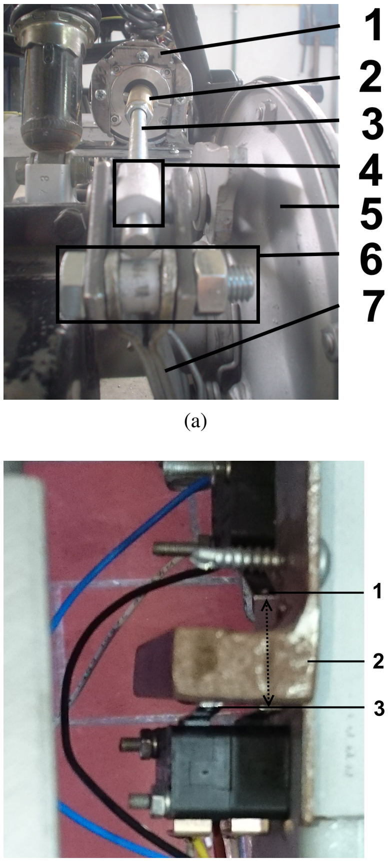
1) Traction speed encoder: To measure the vehicle speed, a variable reluctance sensor was built and attached to the actuator set–up, near the gearbox exit sprocket, as shown in Fig. 2b. It consists of a small permanent magnet with a ferromagnetic pole attached and a copper coil wired around the pole and connected to a Printed Circuit Board (PCB) signal conditioning circuit. When the pole side of the sensor is placed near a metallic rotating teethed gear, an alternating voltage is induced in the coil, which is first rectified and amplified by a half wave precision rectifier, and then converted into a binary signal whose frequency is proportional to the gear speed, by a comparator with hysteresis. A Light Emitting Diode (LED) at the circuit exit provides visual confirmation of motion detection. Sensor consumption was measured at $300\,\mu\mathrm{A}$ at idle and $15\,\mathrm{mA}$ on high frequency operation, and its performance on the final mount at different speeds is shown in Fig. 2c.

D. *Braking mechanisms of the ROVIM*

The vehicle can reduce speed in three different ways: through the original front brake lever, the traction motor controller's regenerative braking feature and the rear drum brake. The first two are used in manual and autonomous driving modes, respectively to reduce the vehicle's speed during normal operation. The rear brake performs emergency braking, and is actuated by a servomotor dimensioned empirically, placed above the rear fork and connected to the brake lever by a worm screw that screws a pivot attached to the lever. The set–up of the rear brake actuator is shown in Fig. 3a. Due to the unidirectional torque transmission characteristics of the screw and pivot set–up, the brake stays locked even when it is not being powered.

Instead of an electronic controller, it is controlled by more transient resilient relays and mechanical switches, arranged in two circuits: a safety mechanism that triggers braking, detailed in II-F1 and a power connection circuit. The brake is connected to the batteries by a polarity switching relay, and the braking polarity leg of the circuit (on by default) is passed through the safety mechanism. The power is fed through end of travel switches mounted to detect each side of the lever travel end, that open the circuit when reached. The set–up of the end of travel mounts is shown in Fig. 3b.

The polarity can be inverted to unlock the brake by a user activated pressure button or a microcontroller signal, that was not connected at this stage.



(a)

(b)

Fig. 3. ROVIM braking subsystem's sensors and actuators.
a) brake actuator mount: 1 – frontal motor fastener; 2 – shaft adaptor; 3 – worm screw; 4 – brake pivot; 5 – brake drum; 6 – pivot's brake lever fastener; 7 – brake lever.
b) brake sensors mount with brake unlocked: 1 – lock side end of travel switch lever; 2 – lever travelling jointly with the brake lever that triggers the switches; 3 – unlock side end of travel switch lever. The dotted arrow denotes the travel of 2.

E. *Steering system of the ROVIM*

The vehicle turns the wheels through a steering column that can be actuated by the original handlebar of the chassis in manual driving mode, or through an electromechanical actuator in autonomous mode. In order to estimate the size of the steering actuator to use, the minimum force required at the tip of the handlebar to turn it from the center position was measured with the vehicle immobilized in a tiled surface. With $25\,\mathrm{N\,m}$ the handlebar moved until about $80\,\%$ of tis course, from which point a $30\,\mathrm{N\,m}$ force was needed to bring it to its end. The torque applied in this situation can be calculated from:

$$
\begin{aligned}
T &= F \cdot a && (8)\\
&= 30 \cdot 0.41 && (9)\\
&= 12.3\,\mathrm{N\,m} && (10)
\end{aligned}
$$

where F is the force applied at the tip of the handlebar and a is the handlebar's radius, measured at $0.41\,\mathrm{m}$. The steering's angular motion range was also measured, at $88.8°$. Having an Ackerman steering geometry, that is designed for the wheels to turn without slip, the torque needed to run the vehicle in motion can be approximated to its rolling resistance torque. Replacing in (4) for the worst case scenario used to estimate the traction actuator:

$$
\begin{aligned}
T &= 400 \cdot 10 \cdot 0.3 \cdot 0.23 && (11)\\
&= 273\,\mathrm{N\,m} && (12)
\end{aligned}
$$

In both the measured and estimated case, the turning torque depends on the friction between the tires and the floor. Since a military vehicle is expected to be rugged enough to drive through a multitude of terrains, the controller of the

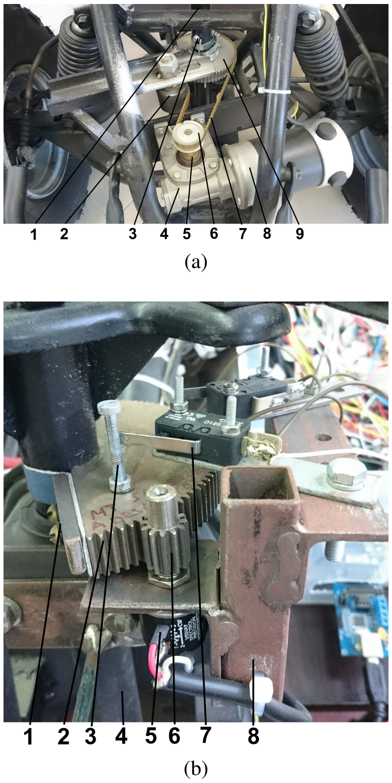


Fig. 4. ROVIM steering subsystem's sensors and actuators.
a) steering actuator mount: 1 – steering column; 2 – belt tensioner; 3 – steering column cut line, where the pulley was inserted; 4 – steering worm drive gearbox; 5 –gearbox's output shaft; 6 – gearbox side dented pulley; 7 – belt; 8 – steering motor; 9 – steering column side dented pulley.
b) steering sensors mount: 1 – gear column fastener; 2 – steering column position's reading gear; 3 – steering end of travel switch trigger; 4 – steering column; 5 – position reading potentiometer; 6 – potentiometer gear; 7 – steering end of travel switch; 8 – sensors mount.

actuator needs to maintain performance across a wide range of changing conditions.

The actuator employed consists of a servomotor connected to a compact worm drive gearbox that drives the steering column through a dented belt connecting two dented pulleys, attached to the gearbox's output shaft and the steering column, totalling a reduction ratio of 98 and allowing a maximum torque of $133.2\,\mathrm{N\,m}$ to be deployed on the steering column. Even though it is smaller than the worst case scenario needs, it was deemed enough and allowed a nimbler actuator to be chosen and mounter lower in the chassis, freeing up area for future expansion needs. The set–up of the steering actuator is shown in Fig. 4a. The motor is driven by an off–the–shelf H bridge power converter designed for robotic applications, in turn controlled through a compatible interface with the microcontroller.

A potentiometer mounted near the handlebar acts as an angular position sensor, driven by a geared connection to the steering column. The same gear is used to trigger two end of travel switches (one at each side) that cut the power supply to the motor and trigger an emergency response, detailed in II-F1. The set–up of the steering sensors is shown in Fig. 4b.

The belt acts as a mechanical fuse, preventing damage to the set–up in case of failure, and the worm drive's unidirectional transmission characteristics act as a terrain irregularities filter. It also means that the steering cannot be driven by the handlebar while the worm drive is engaged, the user having to loosen the belt by means of the adjustable tensioner. Due to poor dimensioning, the belt slips under load (loads lower than $10.25\,\mathrm{N\,m}$ are enough to cause it to slip), severely limiting the design of the control system. Therefore a simple proof–of–concept controller for the unloaded (wheels of the ground) setup was designed.

The microcontroller employed, discussed in more detail in II-F, has a built–in motor position Proportional Derivative (PD) control routine (the integral part is already inherent to the variable under control) that was programmed with a controller with parameters:

$$K_p = 0.594 \tag{13}$$

$$K_d = 1.5 \tag{14}$$

F. T2D's integration electronics

To integrate the capabilities of the actuators, an array of electronic systems were deployed that, in combination with the microcontroller's running program, provide a coherent set of driving, monitoring and communication features. These electronics consist of a relay operated 2 to 1 multiplexer to choose the driving mode, a safety stop mechanism and signal conditioning circuits for the microcontroller signals, all soldered into prototype PCBs, and manual instrumentation, fastened to control panels ergonomically positioned in the vehicle. Most of these systems, along with the brake controller, the microcontroller board and the steering motor driver were wired and grouped in a plastic box, protecting them from the elements and accidental interference.

1) Safety halt mechanism: A safety mechanism controls power delivery to the brake and traction motors in a complementary fashion, and is triggered by an array of controls, available both to a nearby user or a remote controlling computer, ensuring that in case of emergency the system is brought to a controlled halt.

It works by means of a two circuit relay array triggered by each of the possible emergency flags: a dead man trigger, an emergency switch, a signal from the microcontroller, and the end of travel switches. The dead man trigger consists of a fuse sitting on its holder in a unimpeded location, and tied with a long string that also ties to the body of the human user, when it is present, and that in case of vehicle runaway pops and triggers the emergency flag. The emergency switch consists of a standard red and yellow kill switch used in the industry, located at rear of the vehicle, for easier access. The microcontroller trigger is a dedicated output signal from the microcontroller used to trigger a monostable circuit, so that even if the software fails, only a signal pulse is needed to bring the system to a halt. The end of travel switches from the steering set–up trigger a condition when any of them is set, whereas the brake unlock side end of travel switch is used to assure binary operation of the brake, by triggering the safety mechanism when the brake is not fully unlocked.

The steering motor's power delivery is not controlled by this mechanism directly, as it does not pose such a serious threat

TABLE I
ROVIM T2D'S MANUAL CONTROLS.

Type	Function	Possible states
Key switch	Main switch	ON
		OFF
2 way switch	Traction main switch	ON
		OFF
2 way switch	Drive mode selector	Manual
		Auto
3 way switch	Select travel direction [1]	Front
		Neutral
		Reverse
2 way switch	Traction activation switch [1]	Activate
		Block
Pressure button	Unlocks electric brake	Pressed
		Released
Pressure button	Allows steering to be moved in lockdown mode	Pressed
		Released
Emergency switch	Triggers the safety mechanism	Pressed
		Released
Dead man trigger	Triggers the safety mechanism	Alive
		Dead
Hand throttle	Controls vehicle speed [1]	
Brake lever	Brakes the front wheels	
Belt tensioner	Engages the steering actuator	Fastened
		Loose
Pressure button	Reboots the microcontroller	Pressed
		Released

(a)

(b)

(c)

Fig. 5. ROVIM T2D's instrumentation panels.
a) 1 – travel direction selector; 2 – driving mode selector; 3 – traction ON/OFF switch; 4 – traction activation switch.
b) 1 – steering error recovery pressure button; 2 – brake lock indicator; 3 – brake unlock pressure button; 4 – brake unlock indicator; 5 – main ON/OFF key switch; 6 – traction error indicator.
c) 1 –front brake lever; 2 – hand throttle; 3 – Dead man trigger; 4 –emergency switch.

to human lives if out of control. Nevertheless it's end of travel switches, besides triggering this safety mechanism, ensure it's power in also cut in case of a serious error.

2) Instrumentation panels: In order to manually control the operation of the vehicle, an array of manual controls and indicators are available. They are respectively listed in TABLE I and TABLE II and shown in Fig. 5. These serve three main purposes: drive the vehicle, provide basic status information and control its safety mechanism.

3) Microcontroller signal conditioning: Most signals read by the microcontroller are connected to mechanical switches operating at $12\,\mathrm{V}$ and have to be converted to the $5\,\mathrm{V}$ logic of the microcontroller and debounced. This task is performed by a simple resistive voltage divider and low pass RC filter. The voltage divider consists of an upper $74\,\mathrm{k\Omega}$ resistor in series with a ground connected $47\,\mathrm{k\Omega}$ one, ensuring that for the worst case scenario (a new, fully charged battery with a $\approx 14\,\mathrm{V}$ output) the divided voltage remains within the input tolerance of the Integrated Circuit (IC). A ground connected $0.1\,\mathrm{uF}$ capacitor performs a low pass filter with the $28.7\,\mathrm{k\Omega}$ voltage divider equivalent resistor, with $\approx 50\,\mathrm{Hz}$ cut-off frequency, which is enough to filter switch bouncing and provide accurate readings for the microcontroller. The graphics in Fig. 6 show the performance of the circuit. To limit the maximum input voltage to the IC, a clipping diode was connected from the

---

[1] When on manual driving mode.
[2] Only when the brake unlock pressure button is being pressed.
[3] When on autonomous driving mode.

TABLE II
ROVIM T2D's LEDs

Name	Colours	Indicates
Brake unlock	Green	Brake fully unlocked [2]
Brake lock	Red	Brake not fully unlocked
Traction error	Red	Traction motor controller error
Control panel traction error	Red	Same as "Traction error" LED
Traction presence	Green	Traction motor controller is ON
Direction presence	Green	Steering motor driver is ON
Microcontroller presence	Green	Microcontroller is ON
MTR1	Green	Direction and duty cycle of traction motor [3]
	Red	
MTR2	Green	Direction and duty cycle of steering motor [3]
	Red	
LED1	Green	Traction motor state [3]
LED2	Green	Steering motor state [3]
LED3	Red	System error
Travel blink	Red	Vehicle is moving

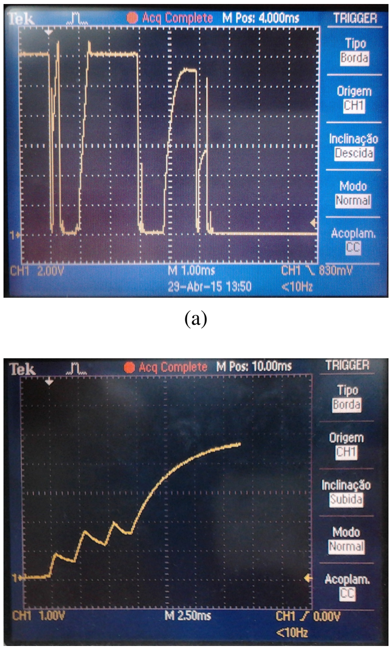
input pin to the circuit's supply.

The traction motor controller expects an analogue signal for both its accelerator and regenerative braking control inputs. To provide that kind of signal, the microcontroller outputs a $10\,\mathrm{Hz}$ Pulse Width Modulation (PWM) signal from a digital output pin that is converted to analogue by a low pass RC filter with a cut-off frequency of $1\,\mathrm{Hz}$. The output analogue signal presents a peak to peak ripple of $\approx 30\,\%$ that shows no hiccups on the output speed because the traction controller is programmed to accelerate very slowly.

G. *Control program*

To provide autonomous driving and system wide monitoring capabilities, a control program was developed by extending the original firmware provided with the microcontroller board acquired. The original is an interrupt–driven, dual motor control program, with an American Standard Code for Information Interchange (ASCII) formatted serial port command interface geared towards human users and an Inter-Integrated Circuit (I^2C) in slave mode binary interface, geared towards control by other computers [6]. The firmware uses almost all hardware resources already, but still was extended, with little loss of original functionality, to control the traction motor controller, trigger the safety mechanism, monitor the sensors in the system and provide an interface to access all these features.

To do so, the hardware signals listed on the TABLE III were routed to the microcontroller board, to provide a means to deploy the new capabilities. On the software, besides extending the interrupt driven command dispatcher, two periodic tasks were created, one providing PWM signals to the traction accelerator and decelerator, and the other monitoring the system and performing delayed actions. The actions performed by the monitoring task are listed on TABLE IV.



(a)

(b)

Fig. 6. ROVIM T2D's microcontroller's input signal conditioning results.
a) mechanical switch bounce. Y axis is switch voltage at $2\,\mathrm{V/div}$; X axis is time at $1\,\mathrm{ms/div}$.
b) filtered and voltage converted switch bounce. Y axis is IC input pin's voltage at $1\,\mathrm{V/div}$; X axis is time at $2.5\,\mathrm{ms/div}$.

The control of the steering position was implemented using the Proportional Integral Derivative (PID) motor control routine of the original firmware, that controls the steering motor driver through it's specific interface. On top of it, a custom function was built to abstract the user from the machine representation of the angular position and the misalignment between the sensor's mid course position and the steering's. The user now only has to specify the desired angular position of the wheels, knowing the angular position's representation: $86°$ being a full starboard turn, $0°$ being a full port turn, and its midpoint, $43°$, now being the direction's mid position.

Acceleration and deceleration controls and a open loop vehicle movement control command were also developed. The movement command allows one of four movement types to be selected: forward, reverse, neutral and immobilization. In order to provide speed readings, the original quadrature encoder reading interrupt had to be adapted to the single source sensor used here, by connecting the quadrature signal input to ground and recalibrating the interrupt.

To mitigate possible software failures, the watchdog was activated, and since the microcontroller's reset signal could not be sourced from the board, the start-up sequence triggers the safety mechanism as early as possible. When it detects or triggers the safety mechanism's activation, the software responds accordingly by forbidding all motor movement and actions not strictly needed to recover from the error detected, what is called the lockdown state. To be able to move the vehicle (either manually or by software), the user has to solve any underlying error conditions and deliberately unlock the brake in coordination with the software. Besides providing a

TABLE III
MICROCONTROLLER'S INPUT AND OUTPUT SIGNALS.

Name	Polarity	Function
Decelerator	Output	Controls regenerative braking [3]
Brake unlocked	Input	Detect brake fully unlocked
Accelerator	Output	Controls traction acceleration [3]
B+	Input	Detects traction controller being powered
Activate Traction	Output	Controls the traction activation switch [3]
Brake locked	Input	Detects brake fully locked
Unlock brake	Output	Unlocks the brake [4]
Steering error	Input	Detects steering out of bounds
Reverse	Output	Selects reverse travel direction [3]
Manual unlock	Input	Detects brake being unlocked by the user
Forward	Output	Selects forward travel direction [3]
Manual mode	Input	Detects manual driving mode selected
Lock	Output	Locks the brake
Emergency	Input	Emergency state detected
Handbrake	Output	Imobilizes the vehicle [3]
Position	Input	Measure direction's angular position
Speed	Input	Measure vehicle speed

TABLE IV
ACTIONS OF THE MONITORING TASK.

Condition	Actions taken	Motive
Speed too high	Goes to lockdown	Slow down the vehicle
Vehicle immobilized and moving [3]	Goes to lockdown	Incoherent state
Emergency state detected [5]	Goes to lockdown	Assure consistency with hardware state
Electric brake neither locked nor unlocked	Goes to lockdown	Enforce binary braking action
Direction end of travel triggered	Goes to lockdown	Assure consistency with hardware state
Taking too long to unlock brake	Goes to lockdown	Precaution
Manual driving mode selected	Stops motors	Avoid unexpected motor movement when reverting to auto mode

high safety standard, this procedure ensures that the vehicle always starts at a known state.

Besides having new commands added, the serial interface was also modified to provide a much more verbose interaction with the user, making novice users's interaction with the program easier. For the advanced user, real time software debug and control features added during the software development stage remain available in the field versions.

III. CONCLUSION

The main goal of this project, to build a functioning prototype of an autonomous, electric vehicle was achieved. Personnel safety was at the forefront of design concerns, and a robust and reliable safety halt mechanism was built, with multiple triggers. Clever packaging allowed a neat component separation, and a hidden battery rack.

TABLE V
USEFUL COMMANDS TO OPERATE THE ROVIM.

Command	Description	Syntax
`G10`	Go to lockdown	`G10`
`G11`	Exit lockdown	`G11`
`G12`	Stop motors, keep configuration	`G12 <mtr#>`
`G13`	Control GPIOs	`G13 <opo><gpio#>`
`G14`	Accelerate	`G14 <%>`
`G15`	Decelerate	`G15 <%>`
`G16`	Select movement	`G16 <dir><vel>`
`G17`	Turn	`G17 <ang>`
`G18`	Debug control	`G18 <op><val1><val2><val3>`
`H`	Help	`H`
`O`	Stop motors, lose configuration	`O <mtr#>`
`X`	Drive motor in open loop	`X <mtr#> <dir><%>`

However, limitations in fabrication methods meant that contact are still unprotected and batteries loose, posing a potential safety threat. Also, failure to build an effective mechanical coupler to the wheels resulted in limited use capabilities for the vehicle.

Access to more advanced battery fixing capabilities, such as auto industry mounts and contact protections, and a steering transmission refitting can solve both problems and achieve a very robust vehicle, with a lot of potential to unlock.

APPENDIX
PROGRAM CODE

An exact copy of the code files of the microcontroller program is available at: https://github.com/ROVIM-T2D/ROVIM-T2D-Brain/tree/v1.0.

ACKNOWLEDGMENT

This project was funded by Academia Militar, a Portuguese public military higher education institution, 1169-203 Lisbon, Portugal. E-mail: (see http://academiamilitar.pt/).

REFERENCES

[1] C. C. Chan, "The state of the art of electric and hybrid vehicles [prolog]," *Proceedings of the IEEE*, vol. 90, no. 2, pp. 245–246, Feb 2002.
[2] N. Hashemnia and B. Asaei, "Comparative study of using different electric motors in the electric vehicles," in *Electrical Machines, 2008. ICEM 2008. 18th International Conference on*, Sept 2008, pp. 1–5.
[3] K. Yiu, "Battery technologies for electric vehicles and other green industrial projects," in *Power Electronics Systems and Applications (PESA), 2011 4th International Conference on*, June 2011, pp. 1–2.
[4] T. D. Gillespie, *Fundamentals of Vehicle Dynamics*. Society of Automative Engineers, 1992.
[5] *Sigmadrive PM Traction Technical Manual*, PG Drives Technology, 2008.
[6] *DALF–1; Rev F Motor Control Board*, Owner's Manual, Embedded Electronics, LLC., Aug. 2008.

---

[4] Currently the pin is not connected.

[5] The safety mechanism has been triggered.

Gonçalo F. R. André is currently a MSc student of Electrotechnic and Computer Engineering at Instituto Superior Técnico, in Lisbon.