


Low-Cost Drive System for Electric Motors based on the IRAM Module

Sistema de Acionamento de Baixo Custo para Motores Elétricos baseado no Módulo IRAM

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Abstract: With the increasing use of equipment that demand electric drive systems, the need for new systems that meet requirements of compactness, versatility, safety and low cost has increased. The IRAM module is an electronic circuit that provides a driver for DC and AC motors, being extremely compact and presents high performance. In this context, this work contributes to the power electronics area, presenting a design and construction of a low cost drive system, based on IRAM module, developed for individual or simultaneous drive, up to two DC motors. To carry out the experiments, DC motors responsible for moving a welding robot, were used. Experimental results are presented to shown the feasibility of using this system.

Keywords: Power Electronics. Drive System. IRAM. DC Motor.

Resumo: Com a crescente utilização de equipamentos que necessitam de sistemas de acionamento elétrico, tem aumentado a necessidade de novos sistemas que atendam requisitos de compacticidade, versatilidade, segurança e que sejam de baixo custo. O módulo IRAM é um circuito eletrônico que fornece um *driver* para motores CC e CA, sendo extremamente compacto e de grande desempenho. Neste contexto, este trabalho contribui para a área de eletrônica de potência apresentando o projeto e construção de um sistema de acionamento de baixo custo, baseado no módulo IRAM, desenvolvido para o acionamento individual ou simultâneo de até dois motores CC. Para a realização dos experimentos, foram utilizados motores CC responsáveis pela movimentação de um robô soldador. Resultados experimentais são apresentados comprovando a viabilidade da utilização do sistema.

Palavras-chave: Eletrônica de Potência. Sistema de Acionamento. IRAM. Motor CC.

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1 Introduction

The task of power electronics is to process and control the flow of electrical energy, supplying voltages and currents appropriately for load (MOHAN; UNDELAND; ROBBINS, 2003). In general, the use of electrical power control systems to drive electric machines and application of industrial controls has grown continuously, causing a change in the concept of power control for energy conversion and driving electrical machines (RASHID, 2014). Currently, due to the high use of technological equipment that require electric drive, highly effective drive systems are required, which meet safety issues, in addition to being compact and versatile units. Thus, they enable the application of electric machines in the most diverse equipment and robots, meeting the requirements of their loads.

With growing study on last decades, some components appear meeting these needs. One of them, the IRAM module, was designed to improve the application of motors drive and speed control (INFINEON TECHNOLOGIES AUSTRIA AG, 2017). This module is a hybrid integrated circuit that provides a high performance driver for DC or AC motors, acting in the motor power stage development. Due to its high compactness and versatility, it is commonly used on industrial applications (RIEHL, 2010).

Since many industrial equipment have extremely expensive and exclusive drive boards, new alternatives related to power electronics have been studied in the literature. In (LU et al., 2007), it is presented a detailed implementation of a very-low-cost multisolver hard real-time simulation environment. The authors proposed an efficient real-time hardware-in-the-loop testing approach for controller designs in power electronics applications. For validation purposes, the system was applied in two power electronics examples: a boost converter and a H-bridge inverter. The experiments were made in these devices with their respective control systems, representing a very low-cost and a relatively advanced hardware setup. The experimental results proved the applicability of real-time extension of the virtual test bench and proposed testing approach. In (RADUN, 1995), a lightweight and low-cost current sensor for application in high-current/high-frequency inverters and power converters is described. It was made an implementation of the current sensor for a unidirectional current switch and the results demonstrated its feasibility for use on high-power motor drive applications. Moreover, in (CHAKRABORTY; KRAMER; KROPOSKI, 2009), it was made a review of power electronics interfaces for distributed energy systems towards achieving low-cost modular design. Then, different power electronics topologies, that are typically

used with distributed energy systems, were discussed. The authors explained that it is expected that modular and flexible power electronics and standardised controllers and interfaces, will provide commonality in hardware and software for power electronics interfaces. Thus, it will enable their volume production and decrease their cost share in distributed energy applications.

In this context, the IRAM module, due to its characteristics, becomes a great option for a low cost alternative drive system, which can be used in several applications with DC or AC motors (single-phase or three-phase). In this context, this work presents a proposal for a drive system, based on the IRAM module, developed for two DC motors, with the module being used in the power stage development of each motor used.

The organisation of this work is given as follows: in Section II, the IRAM electronic module is presented, as well as its physical and electrical characteristics. Next, on Section III, it presents the proposed drive system design, including schematic and layouts of the developed circuits. Besides, in Section IV, experimental results provided from DC motors application are presented. Finally, in Section V, the conclusions of this work are presented.

2 IRAM Electronic Module

The IRAMS10UP60A module is an integrated circuit developed by manufacturer *International Rectifier*. This module, treated simply as IRAM throughout this work, is used for electronic control of motors, and can be applied in washing machines, refrigerators, among other machines (INTERNATIONAL RECTIFIER, 2012).

This module is a HIC (Hybrid Integrated Circuit), that is, it has both analogical and digital circuits inside its enclosure. In general, the IRAM module consists of six bipolar IGBT (Insulated Gate Bipolar Transistor) connected in a three-phase inverter bridge, representing three inverter arms. It is emphasised that IGBT transistors are generally applied in the control of power devices, such as solenoids, motors and other important applications, where is fundamental controlling the high currents.

The main technical characteristics of the IRAM module are:

- Module supply voltage: 15 V;
- IGBT blocking voltage: up to 600 V;

- Positive input voltage on the bus: up to 450 V;
- Effective current: up to 10 A_{RMS} ;
- Maximum temperature: 100°C;
- Maximum peak current: 15 A;
- Maximum PWM frequency: 20 kHz.

Being a highly reliable device, the IRAM module has a built-in temperature monitor, based on an NTC (Negative Temperature Coefficient) thermistor and over-temperature/over-current protection. In addition, it has an integrated insufficient voltage blocking function, which offers a high level of protection and safety to the circuit. The internal electrical schematic and pinout of the IRAM module can be consulted at (INTERNATIONAL RECTIFIER, 2012).

The IRAM module has three inverter arms for motors drive (or three pairs of switches/transistors), which are controlled by PWM (Pulse Width Modulation) signals. This configuration allows single-phase or three-phase DC or AC motors to be driven, among others.

To control a DC motor velocity, the PWM (Pulse Width Modulation) Duty Cycle is varied, allowing to obtain average values of continuous voltage within the power limit of the module bus. In addition, it is possible to connect a DC motor with full-bridge drive or two DC motors with half-bridge drives. In this work, the IRAM module is used to drive two DC motors, using a half-bridge topology with PWM triangular modulation.

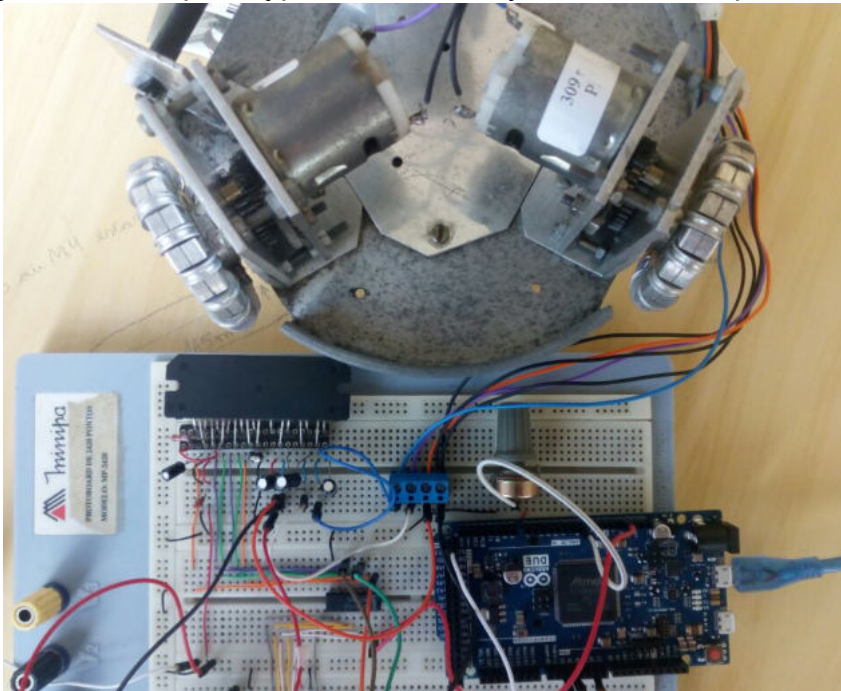
The drive circuit half-bridge allows the load to be supplied with up to half applied voltage (positive and negative). In addition, it has only one inverter arm, composed of a pair of switches, connected in anti-parallel with diodes, which operate in a complementary way. The second arm consists of two voltage sources that generating voltage midpoint on the motor. Ideally, the voltage midpoint for motors is made with two capacitors. However, in this work, it was created with an auxiliary arm configured with PWM standard at 50%.

3 Drive System Design

Before starting a drive system board prototype, an experiment was carried out, where the system was developed in a protoboard. For this, the typical connection

for a three-phase AC motor, provided in the IRAM datasheet, see (INTERNATIONAL RECTIFIER, 2012), was implemented. The first experiment was carried out with DC motors, being the test platform a football player robot. In this way, some adjustments were made to the connection, and prototype was built in protoboard, as shown on Figure 1.

Figure 1: Initial prototype of the drive system built with protoboard



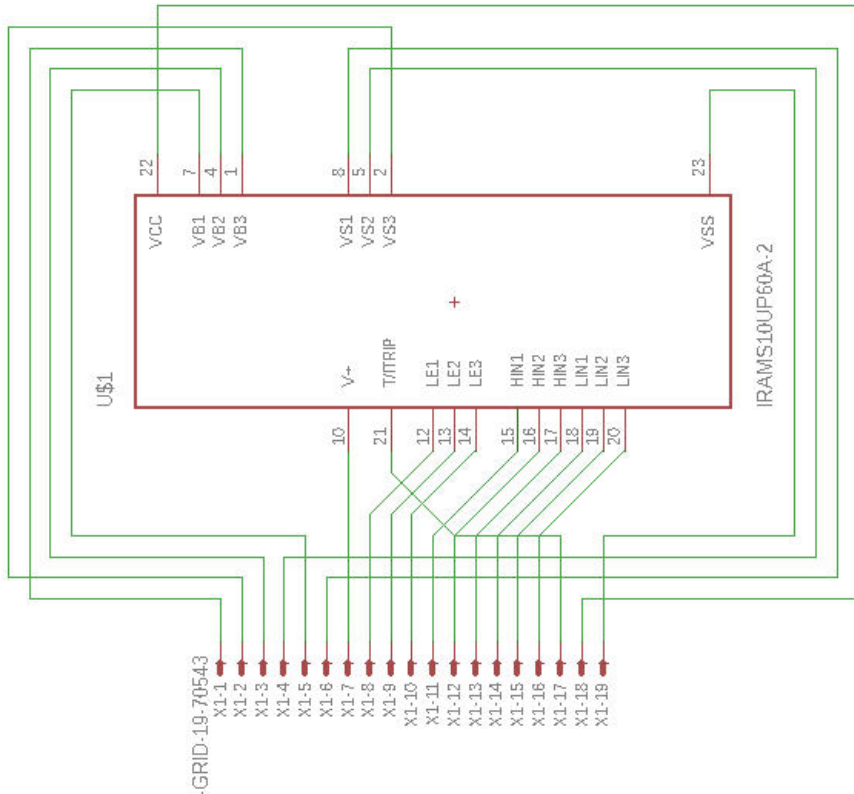
Source: adapted from (PAULA et al., 2018)

One of the issues to be highlighted is that IRAM module does not work with voltage below 12 V , being necessary to check the output voltage value of DC-DC converter. Therefore, it is recommended to keep power supply always slightly above 12 V required to the IRAM module supply. In addition, the system is highly sensitive, and any minimal bad contact presented on system impairs, will affect the rotation for both sides of the motor. Furthermore, the presence of a badly connected capacitor can also alter motor rotation. Thus, these initial tests were essential for making necessary adjustments to the circuit. After it, the drive system circuits development begins.

For schematic and layouts development of the circuits, necessary for drive system construction, the Eagle software was used. During the adjustment stage, it was noticed that IRAM module has two lines of pins curved at 90° , which disturbs its stability when connected directly to the board. Since it could interfere on drive system operation, an adapter was constructed for the module, in order to better fix it on system board. In this

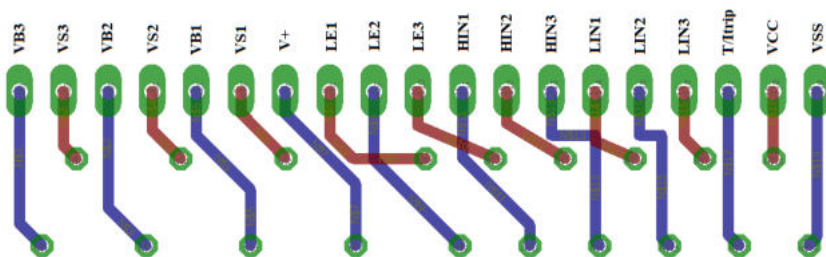
way, the IRAM adapter consists of a single 19-pin bus, which is plugged to the module pins. The adapter schematic is shown on Figure 2, and its circuit layout is presented on Figure 3.

Figure 2: IRAM module adapter schematic



Source: From authors

Figure 3: IRAM module adapter layout

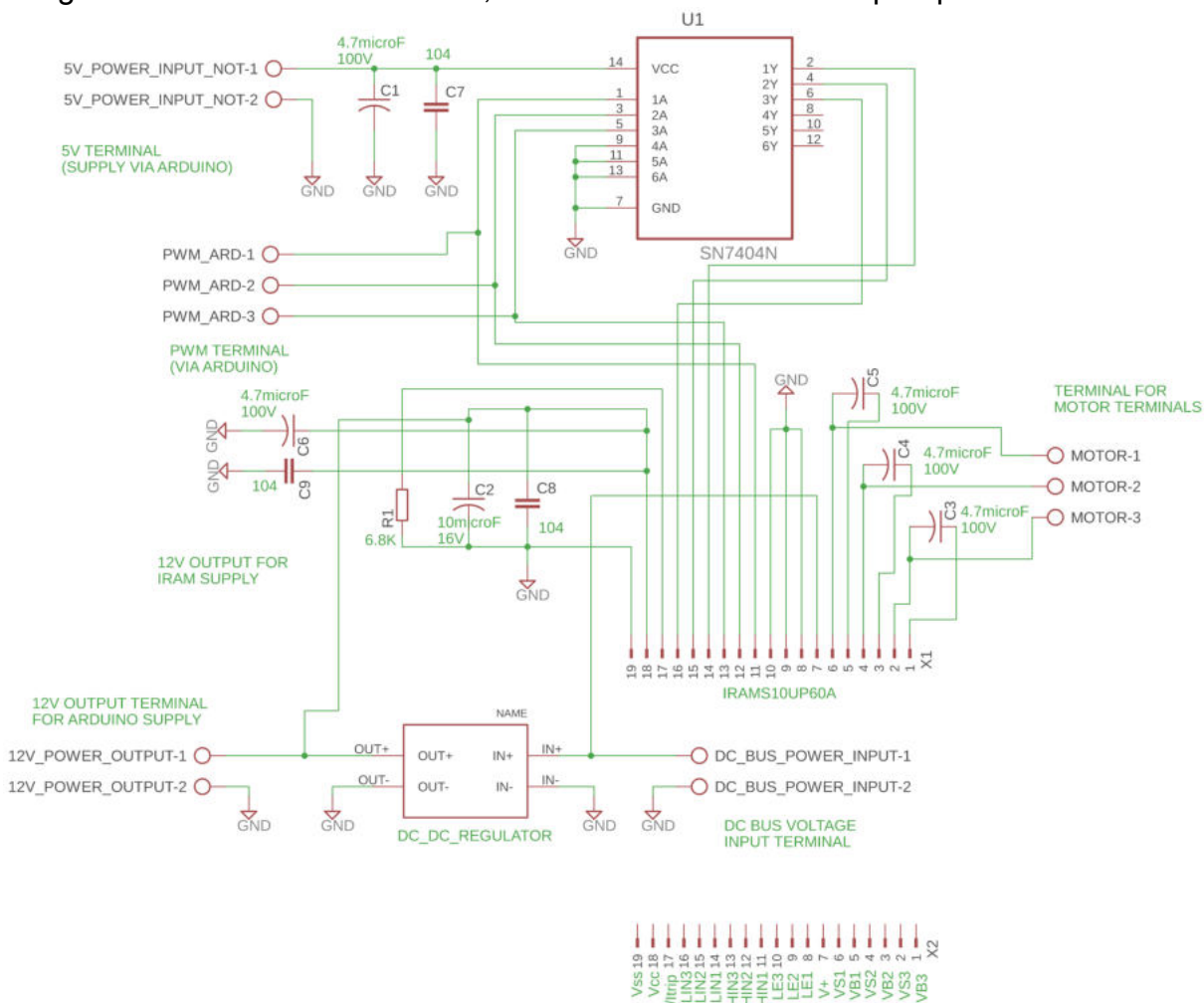


Source: From authors

After tests, it was noticed that adapter subserves the module connection. Through a single bus, module is integrated to the board, allowing a firmer connection and making a more robust and reliable signal transmission. For a better understanding, it is possible to see on Figure 4, below general circuit diagram, a pin bus (1 to 19). This bus

corresponds to the sequence of pins resulting from adapter, where the name of each pin is indicated in relation to the IRAM bus on general circuit. Thus, after adapter be built, the drive system schematic was defined using Eagle software, as shown on Figure 4.

Figure 4: Drive circuit schematic, with the IRAM module adapter pins identification



Source: From authors

This schematic follows the typical IRAM connection, however it has necessary adjustments for connection of IRAM module with Arduino Due. For this, a voltage regulator module LM2596 is used, operating as a DC-DC converter, where output voltage can be adjusted through a potentiometer, between 1.5 to 35 V, having input between 3.2 to 40 V. Its objective is provide 12 V for IRAM and microcontroller board.

When two semiconductors are arranged in the arm, the generation of a complementary signal is necessary because switches activation is performed in an

inverse way (AHMED; AMEI; SAKUI, 1999). Therefore, a NOT logic port is used to generate a complementary signal, a parameter of the PWM modulation. Then, a 7404 inverter circuit is used as logic port and, in order to optimise the design, it receives power from Arduino board.

In the system, decoupling capacitors are also used in the power input of NOT logic port and IRAM module, which aim to prevent high frequency noise from influencing such signals, thus making them more stable. In Figure 4, these capacitor sets can be seen at the power input of the two integrated circuits, one being electrolytic and other ceramic one.

The terminals present into circuit have the following purposes:

- DC_BUS_POWER_INPUT: DC bus power input, up to 600 V (IRAM limit), but limited to 40 V by the DC-DC regulator;
- 12V_POWER_OUTPUT: 12 V power output for Arduino and IRAM;
- MOTOR: connection of the motor terminals;
- PWM_ARD: PWM signals input;
- 5V_POWER_INPUT_NOT: 5 V power input, coming from Arduino to NOT logic port.

Both boards, main drive and adapter for IRAM module, were handcrafted in the laboratory. The Table 1 shows the description of the drive board connectors by IRAM.

Table 1: Description of the drive system board via IRAM connectors

Connector	Description
<i>Arduino Due</i>	12 V power output for the <i>Arduino</i>
DC Bus	DC bus power input, up to 600 V (IRAM limit), but limited to 40 V by DC-DC regulator
Motors	Connection of motor terminals
NOT port	5 V power input, coming from <i>Arduino</i> to NOT logic port
PWM signals	PWM signals input

Source: From authors

4 Experimental Results

This Section presents the experimental results, obtained from DC motors driving application. The parameters of both motors are presented in the Table 2. These

parameters were identified experimentally, following the same steps discussed on (FERREIRA et al., 2020).

Table 2: Motor parameters

Motor M1			
Symbol	Value	Standard deviation	Unit
R_a	4.91	3.348E-01	Ω
L_a	13.300E-03	–	H
B	1.278E-04	–	$(kg\ m^2)/(rad^2\ s)$
J	2.713E-05	7.235E-06	$kg\ m^2$
K_t	3.423E-02	8.040E-03	$(N\ m)/A$
K_v	3.423E-02	8.040E-03	$(N\ m)/A$
Motor M2			
Symbol	Value	Standard deviation	Unit
R_a	3.74	1.176	Ω
L_a	13.300E-03	–	H
B	2.218E-05	–	$(kg\ m^2)/(rad^2\ s)$
J	2.194E-05	3.858E-06	$kg\ m^2$
K_t	1.614E-02	3.432E-03	$(N\ m)/A$
K_v	1.614E-02	3.432E-03	$(N\ m)/A$

Source: From authors

To realise this experiment, two DC motors, responsible for the movements of a welding robot, were used. By convenience, the motors are called as *M1* and *M2*. Initially, they were triggered individually, as explained in Subsections 4.1 and 4.2. Then, both motors were driven, as shown on Subsection 4.3.

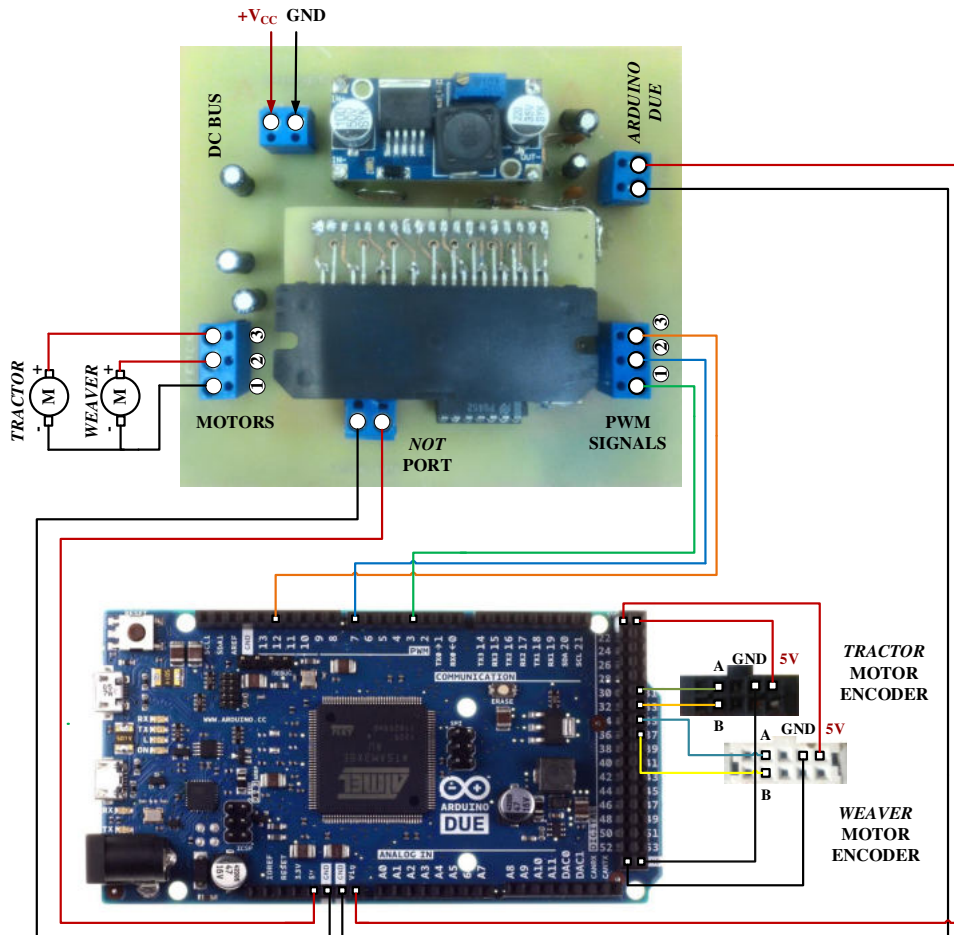
Figure 5 presents detailed connection between drive, control and data acquisition systems. Although drive was initially carried out individually for each motor, the used inverter arms configuration was maintained according to the previously presented.

In the experimental tests, a DC bus voltage equal to 30 V was applied. Thus, with the half-bridge drive, the voltage range obtained for motors was an interval from –15 to 15 V, operating voltages of the motors. It is emphasised that PWM frequency used in the microcontroller was set to 10 kHz, aiming to reduce audible noise.

4.1 *M1* motor drive

The Figure 6 shows the bench used for testing drive system applied to the *M1* motor. This activation was performed using the 1 and 3 inverter arms of IRAM module, as shown on Figure 5.

Figure 5: Wiring diagram of the drive, control and data acquisition system



Source: From authors

Figure 6: *M1* motor drive experiment



Source: From authors

On initial tests, the armature voltages values were varied from -15 to 15 V. Then, the voltage at motor terminals was measured and a variation was noticed between it and desired voltage. This difference is due to the voltage drop required to activate IGBT

switches. Therefore, it was necessary to perform a calibration. Figure 7(a) shows ideal and real curves between desired and measured armature voltages. Also, the relation between them, considering polynomial degree equal to 1, is given by

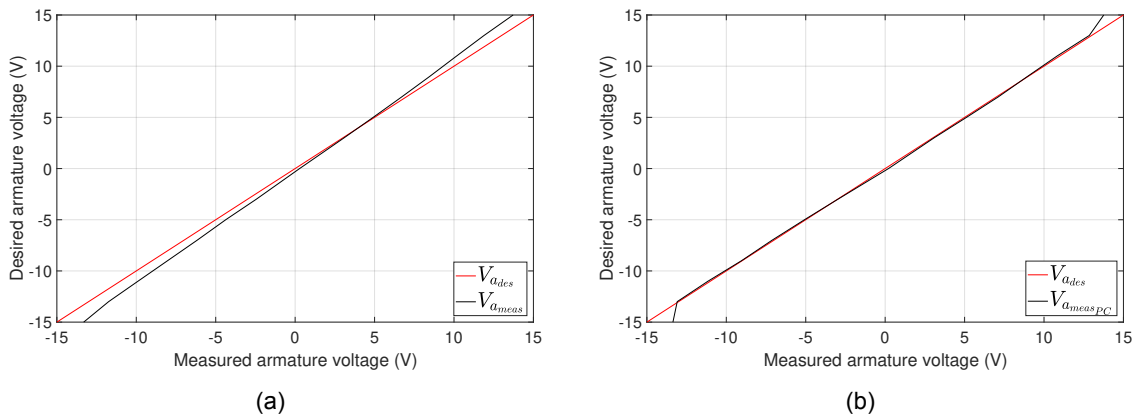
$$V_{a_{meas}} = 0.9094 V_{a_{des}} + 0.2180, \quad (1)$$

where $V_{a_{des}}$ is the desired armature voltage and $V_{a_{meas}}$ is the measured armature voltage at the motor terminals. In this way, this equation was used to correct the difference between desired and measured voltages during PWM signal generation stage. Thus, the corrected voltage to be applied so that the measured voltage is equal to the desired voltage is given by

$$V_{a_{cor}} = \frac{V_{a_{des}} - 0.2180}{0.9094}, \quad (2)$$

where $V_{a_{cor}}$ is the corrected voltage to be applied at the motor terminals. Next, voltage steps between -15 and 15 V were applied again and the new curve found between desired and post-correction measure voltages is shown on Figure 7(b).

Figure 7: *M1* motor armature voltage curve (a) before and (b) after calibration



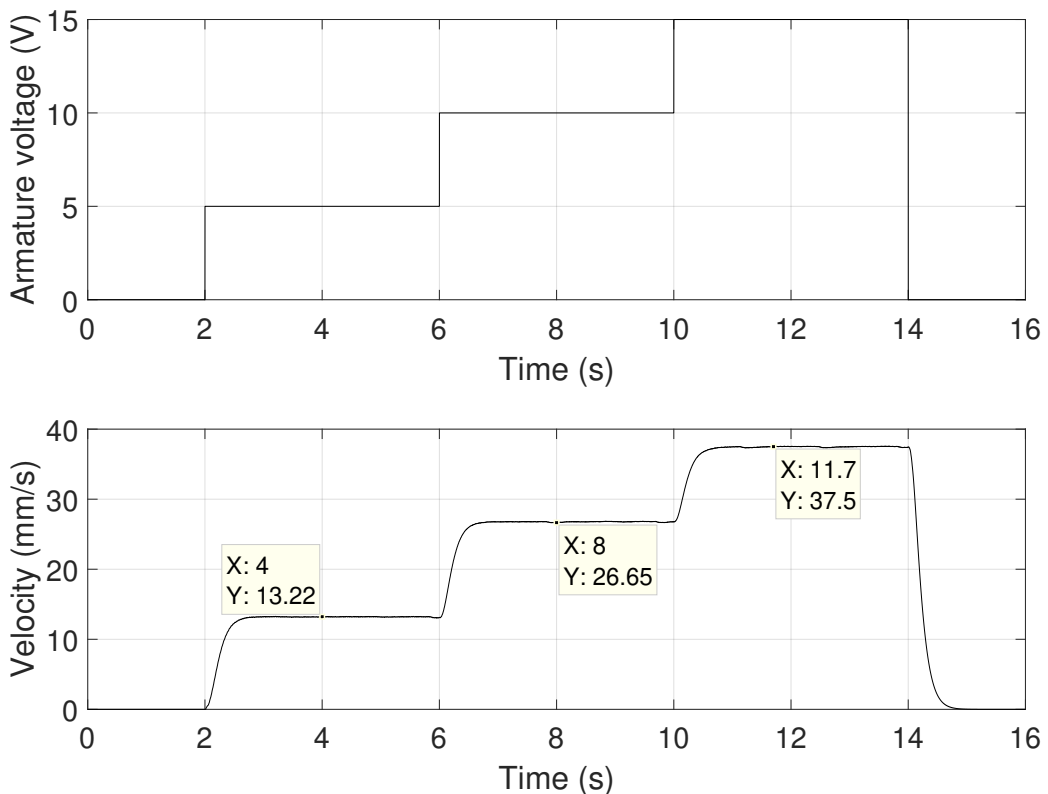
Source: From authors

As can be seen, the similarity between curves has increased, with greater equivalence between desired and measured armature voltages. It is emphasised that difference on limits of the curve appears because, at these points, the required armature voltage was greater than maximum voltages (15 or -15 V). It is noteworthy mention that this calibration is unique for the inverter arms and motor combination. In this way, the arm configuration was maintained during all tests.

For greater verification of the motor behaviour when driven by proposed system, tests were carried out. It consisted on applying voltage steps of different values, in

a short period of time. The following result presents a test in which armature voltage steps equal to 5, 10 and 15 V were applied. This test was performed during 16 s, with a step of 5V applied at 2 s; 10 V at 6 s and 15 V at 10 s. For better visualisation of motor behaviour during transient response, velocity values were collected. Figure 8 shows armature voltage and linear velocity curves collected, besides, values on steady state are marked.

Figure 8: Results obtained in the application of voltage steps in the M1 motor with drive via IRAM: positive steps equal to 5, 10 and 15 V

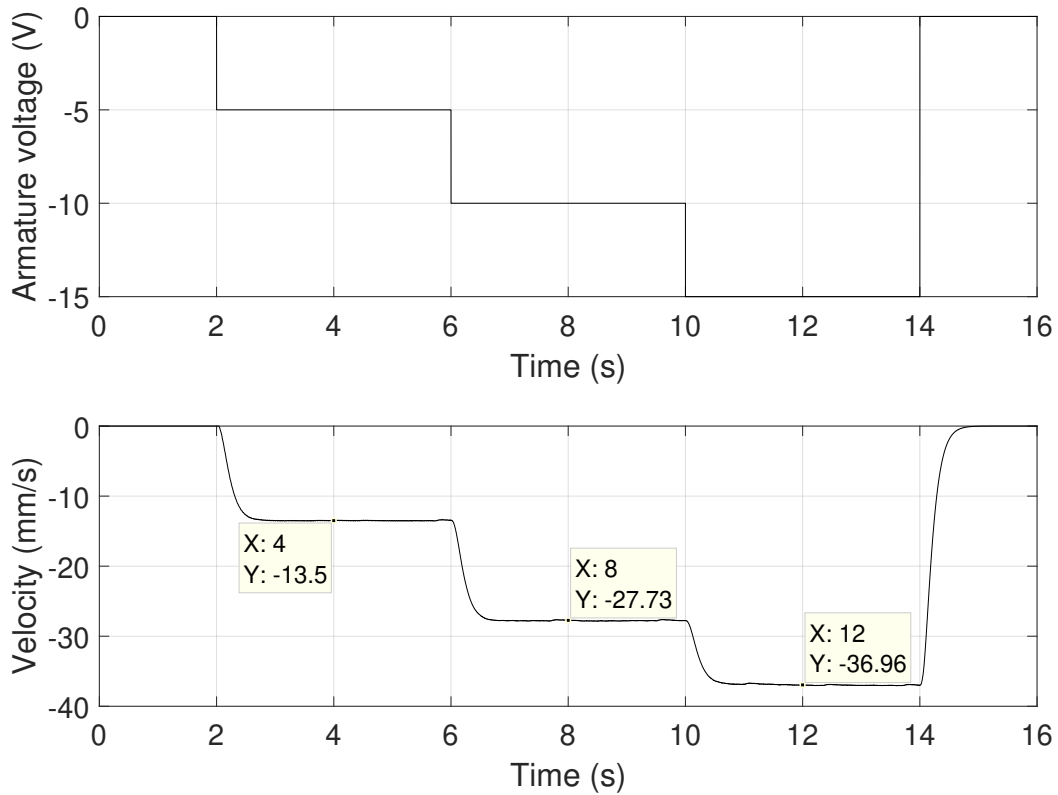


Source: From authors

These same tests were performed in the reverse direction of the motor, with application of steps equal to -5 , -10 and -15 V, whose collected curves are shown on Figure 9.

As can be seen, the proposed system enabled a robust drive, resulting in quick responses to the applied voltage steps. In both directions of motor rotation, the time constants were less than 300 ms. In addition, steady-state velocities were similar for both directions, regardless of the voltage step applied.

Figure 9: Results obtained in the application of voltage steps in the *M1* motor with drive via IRAM: negative steps equal to -5 , -10 and -15 V



Source: From authors

4.2 *M2* motor drive

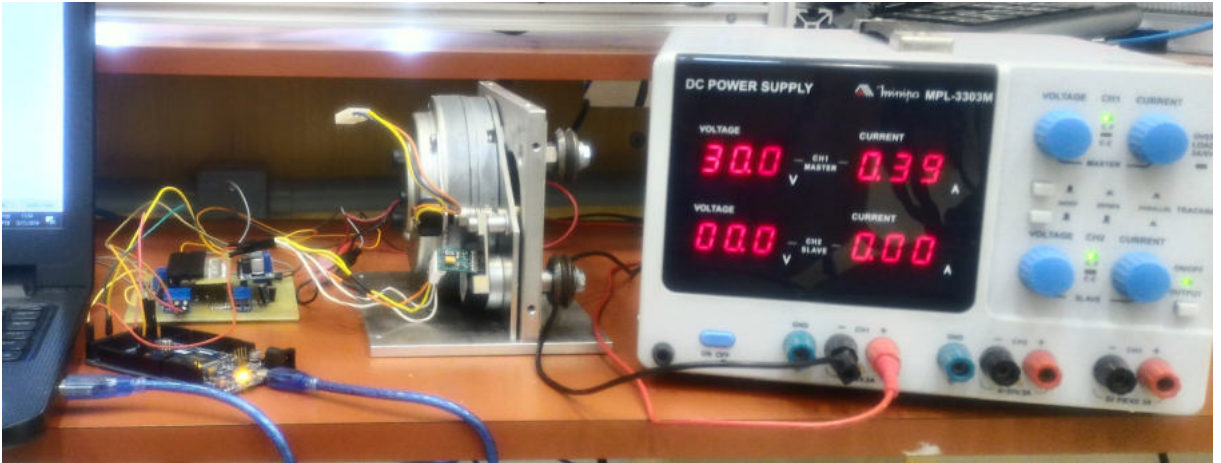
Figure 10 shows the bench used for testing drive system applied to the *M2* motor. This activation was performed using the 2 and 3 inverter arms of the IRAM module, as shown on Figure 5.

For this motor, a calibration was also required. Figure 11(a) shows the ideal and real curves between applied and measured armature voltages. The equation, which represents the real curve obtained, is given by

$$V_{a_{meas}} = 0.9176 V_{a_{des}} + 0.1353. \quad (3)$$

This equation was used to correct the difference between desired and measured

Figure 10: M2 motor drive experiment



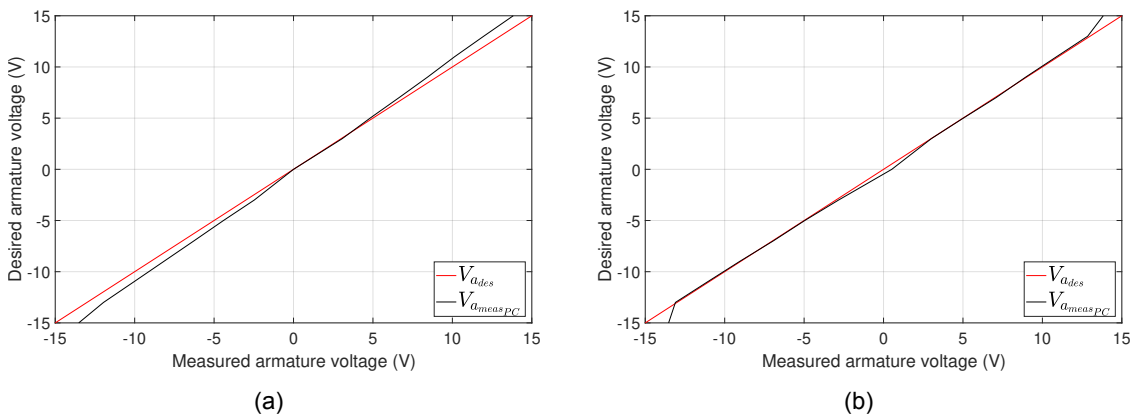
Source: From authors

armature voltages. Thereby, the corrected voltage to be applied is given by

$$V_{a_{cor}} = \frac{V_{a_{des}} - 0.1353}{0.9176}. \quad (4)$$

After applying the steps again, the new curve found is shown on Figure 11(b).

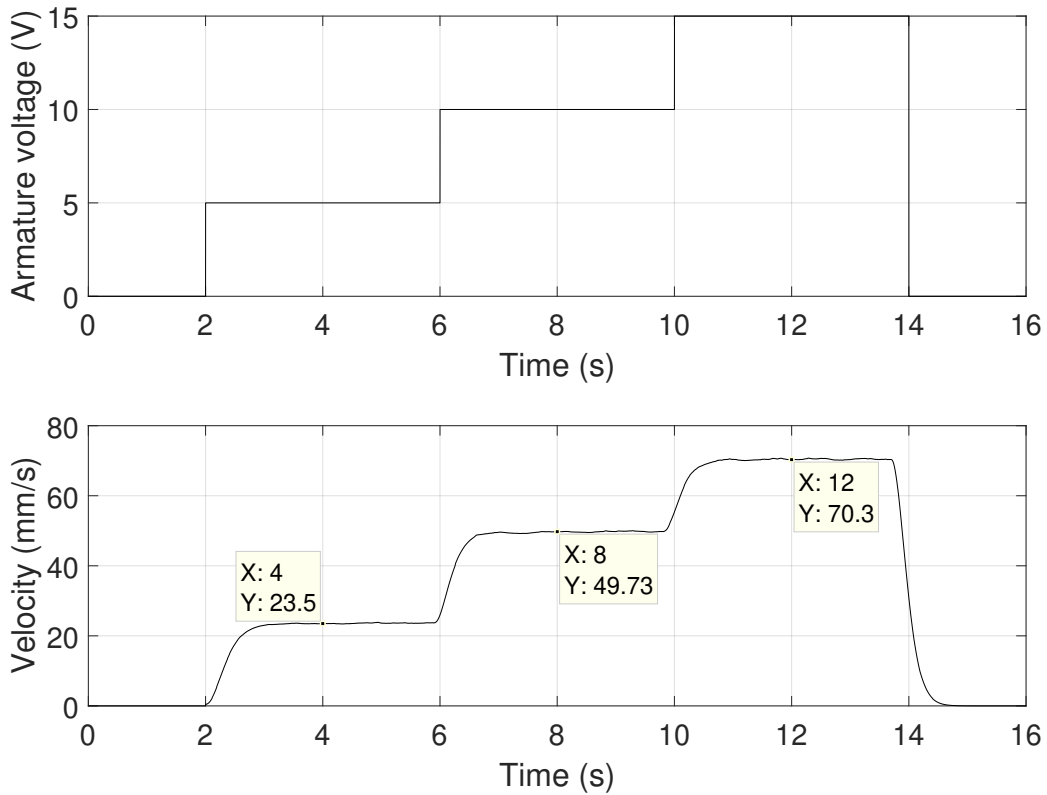
Figure 11: M2 motor armature voltage curve (a) before and (b) after calibration



Source: From authors

The same tests, previously described, were performed for motor M2. Thus, Figure 12 presents curves collected in the application of positive voltage steps, and Figure 13 shows those data collected in the application of negative steps.

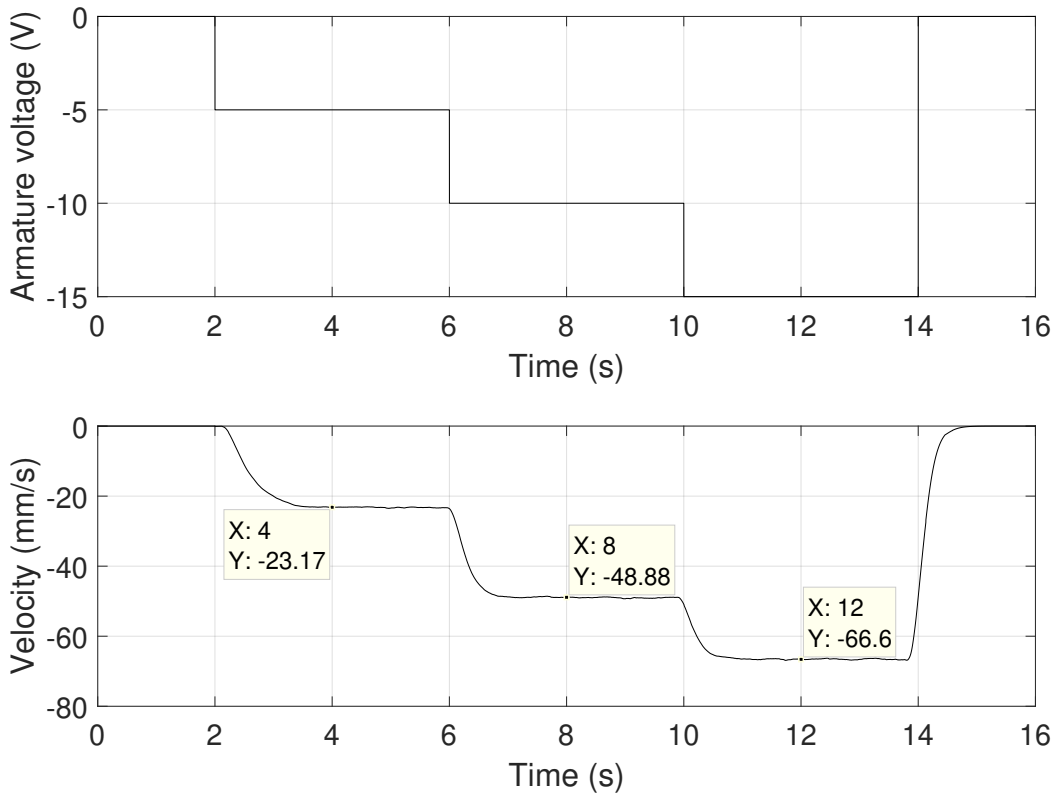
Figure 12: Results obtained in the application of voltage steps in the *M2* motor with drive via IRAM: positive steps equal to 5, 10 and 15 V



Source: From authors

Analysing the curves, it was noticed that proposed system also enabled a robust drive for motor *M2*. However, there was a greater variation between time constants, being higher for steps with less voltage and smaller for those with greater. Thus, it can be concluded that responses were faster on application of greater voltage. Still, considering the two directions of motor rotation, time constants were less than 700 ms, which depends on moment of inertia and load of motor, as well as supplied armature current, constructive constant and other motor parameters, not the drive itself. In addition, a slightly lower velocity range in the negative direction was noted.

Figure 13: Results obtained in the application of voltage steps in the *M2* motor with drive via IRAM: negative steps equal to -5 , -10 and -15 V



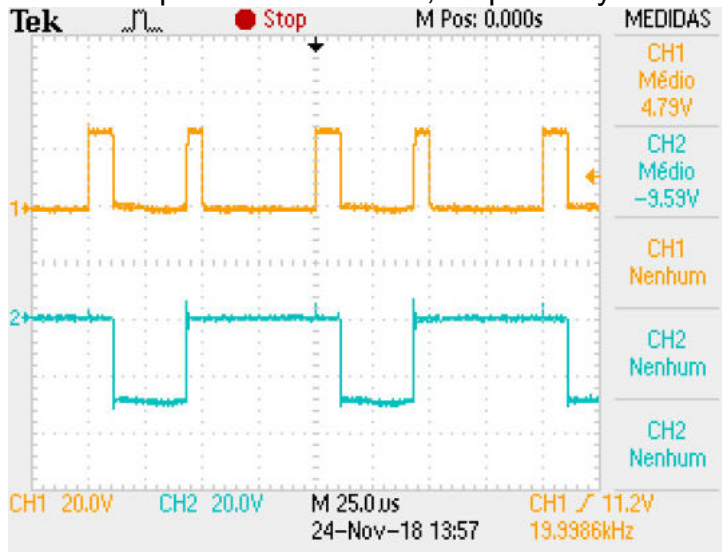
Source: From authors

4.3 Both motors drive

For both motors drive, the configuration of arms was maintained, as previously explained. The motor *M1* was connected to the 1 (*B1*) and 3 (*B3*) inverter arms, and motor *M2* was connected to the 2 (*B2*) and 3 (*B3*). In this way, the motors can be controlled independently. To validate, the following test is an experiment in that voltages of 5 and -10 V were applied to the motors *M1* and *M2*, respectively. Through an oscilloscope, PWM waves applied to the motor terminals were collected. Figure 14 shows such waves, being the orange wave collected from the motor *M1*, and the blue one from the motor *M2*.

As can be seen, in the measurement menu, the average voltage values of each motor were equal to 4.79 and -9.59 V, approximate values of the desired voltages. In this way, the independent control of the motors driven by the proposed system is achieved.

Figure 14: PWM signal waves applied to the $M1$ and $M2$ motors to apply voltages equal to 5 and -10 V , respectively



Source: From authors

5 Conclusion

This work presented a proposal for a drive system for motors based on the application of the IRAM electronic module. For experimentation purposes, the system was used to drive and control two DC motors of a welding robot. The module was presented, along with its characteristics and, then, all the stages of drive system design were presented, considering circuit details, as well as schematic and layouts of the manufactured plates. Experimental results were carried out to validate the alternative drive system, which demonstrated the system's feasibility and effectiveness in performing a robust drive and with quick responses to applied voltage variations. Thus, the system is a feasible low cost alternative for driving and controlling motors, presenting an acceptable performance. In addition, as it is a versatile system, it becomes a great engineering teaching platform, to be used, for example, in experimental classes of power electronics disciplines.

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