Motor speed control of titanium tape using bluetooth and a pulsed x-ray table-top source

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***Abstract*—Since the aim of mechatronics is to improve the functionality of technical systems, it may be used to implement a rotation speed control of a titanium tape in an embedded system, in order to capture femtosecond x-ray pulses from a table-top laser source. This embedded system has application in multidisciplinary areas as in biological systems, where structural dynamics of myoglobin can be better understood by the capture of information about the photo-excitation of carbon monoxide, for example. A low cost embedded system may increase accessibility in the use of the information stored in the cells and its chemical and biological reactions concerning, for example, the human body, once the price of the final system would not be too high. Then, the control the titanium tape's rotation speed allows the correctly understanding of interesting phenomena which are found in the sup-picosecond time scales not available for synchrotron techniques, by registering femtosecond x-ray pulses, which means that a refined analysis of unknown info may be made afterwards, impacting positively not only the academic domain by the knowledge acquired, but also the society.**

Keywords*—*Femtosecond, Pulsed X-ray, Modeling, Bluetooth, Embedded Systems.

I. INTRODUCTION

THE purpose of this paper is to present the embedded system developed to control a mechatronics system used to capture femtosecond x-ray pulses, as a project of the Embedded Systems Laboratory Project Course [1] at "FEM" - Faculty of Mechanical Engineering in partnership with "Gleb Wataghin" Institute of Physics, both at University of Campinas - UNICAMP, Campinas, Brazil. Advanced synchrotron radiation techniques are being developed to obtain refined analysis in materials science, so one particular case of study is devoted to obtain time resolved information using the sub-nanosecond x-ray pulses from bunches of the synchrotron storage ring, allowing to probe picosecond dynamics of systems in multidisciplinary areas. Interesting applications within biological systems are the dynamics of the isomerized cis-trans conformation of rhodopsin found in human eyes, or the structural dynamics of myoglobin by the photo-excitation of carbon monoxide. Unfortunately interesting phenomena is found in the sup-picosecond time scales, which is not available for synchrotron techniques. An interesting complementary tool is the use of a table-top laser based femtosecond x-ray sources being developed worldwide. At UNICAMP a prototype of this source has been developed, where x-ray pulses are produced by the interaction of 1 [mJ], 60 [fs] near infrared pulses focused at a titanium tape target at 1 [kHz] repetition rate.

The implementation is made by using the Kinetis Software Design Studio [6] to test, compile, and build the embedded system. It will be implemented on FRDM-KL25Z4 NXP Board platform [2] and will use C language, as well as libraries provided by NXP. The project is divided by 6 parts, which are highlighted in the following sections.

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II. PROJECT DESIGN

In this chapter we discuss how was the evolution of the gerneral idea for this project.

A. Femto before the project

The Femto project consists of a target tape of titanium. On being hit by high-speed photons coming from a laser, the titanium extracts electrons when photons collide with their atoms, caused by the rapid deceleration of the laser photons. This process triggers the x-ray generation through the phenomenon of Bremmsstrahlung [3]. The project's objective is to generate pulsed x-ray beam using a pulsed laser source.

When colliding with laser photons, the titanium degrades. Therefore it is necessary that the titanium be constantly replenished in front of the laser. For that it is used a system of tapes, where two DC motors [4] scrolls the titanium tape, maintaining a constant tangential velocity. As the focus of the laser is very small (20 μm), vibrations on the tape are not tolerated by the system because the laser should focus exactly on the tape. For motor control was used the C-863 PI module [5].

As the tape rolls diameter varies when the tape is winding and unwinding, it was necessary to compensate the motor speed in order to correct the tangential velocity, and titanium tape should always be tensioned.

B. Initial Proposal

It was initially proposed the implementation of PID controllers in the system to control the DC motor so that the tangential velocity of the tape and mechanical stress would follow pre-defined values.

Looking more closely to the system of titanium target tape, we realized that the problems presented above could be solved mechanically, without the need of implementing a dedicated controller. Two DC motors taken from printers have been added with the function of maintain the tape tensioned and rolled. The controlled DC motors are coupled to two rolls in order to maintain the target tape straight in direction of the beam.

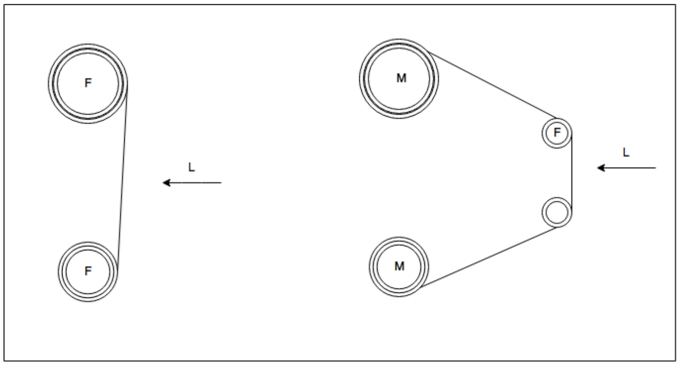

Fig. 1. Femto before and after the mechanical modification. M is the print motor, F is the Faulhaber motor, and L is the laser beam.

C. Reviewed Proposal

By further studying the dynamics of Femto, we realized that we could improve it in other ways. The C-863 module used for motor control was completely underutilized. It has features such as position control, internal memory, joystick interface, brake control and many others that are not necessary in the Femto system. Besides, this module has a price of approximately R$3000,00 (600 euros). We found out that it is possible to decrease the price of the project considerably through the replacement of the module by a H-bridge circuit and PWM control. Also we included in the project the opportunity to drive via Bluetooth. Despite the fact that Femto does not generate sufficient x-ray intensity to be considered dangerous, we find interesting the possibility that the Femto system is operated without a person close to the x-ray source. We also added to the project scope a beep that alerts when the system is in operation.

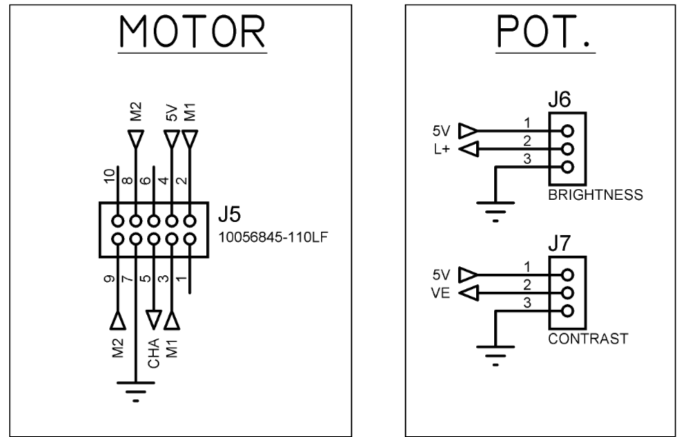

Fig. 2. Motor and Power Module Schematic Diagrams.

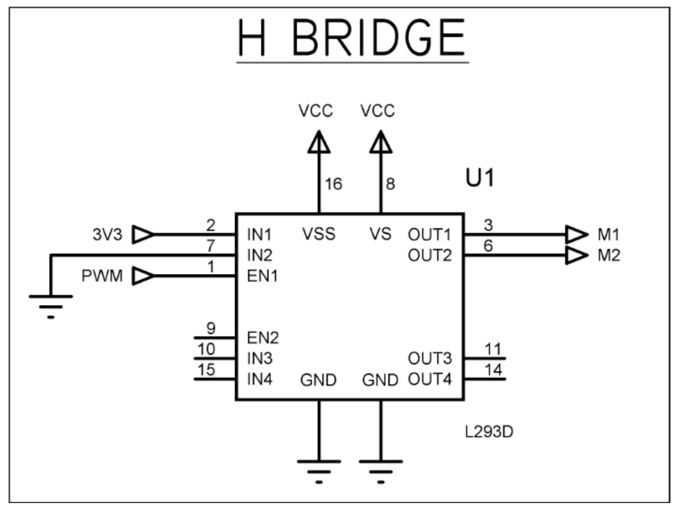

Fig. 3. H-Bridge Schematic Diagram.

III. Targets : Schematics and Circuits

The engine used [4] has power supply of 25V and an encoder with two channels. For this stage of the project we will use only one encoder channel to have a speed feedback.

The motor is powered through a H bridge circuit switched through the board by a PWM pulse. It is necessary a voltage divider circuit to adjust the voltage of the source to the encoder working voltage.

For the Bluetooth module [9], a voltage regulator circuit was necessary to maintain the stability of the power supply. The modules RX and TX ports were connected to the boards UART ports. Through the BlueTerm [10] application was possible to send and receive data via serial communication between the Bluetooth module and an Android phone.

It has also been used a buzzer to serve as alarm when the system enters into operation. The buzzer was connected directly to the microcontroller, with a diode in antiparallel to avoid current return induced by its internal coil.

We seek the maximum reuse of the codes developed during the laboratories to optimize the work. Thus, the ports used for each peripheral resemble the connections of peripherals used in the laboratory.

IV. Implementation

We use the Bluetooth module as UART (Universal Asynchronous Receiver Transmitter) using the RS232 protocol with baud rate of 9600 bps. The controller interprets the received characters one by one. The commands are the following:

- VS: Start the system, powering the engine with PWM 100%, triggering the LCD with the PWM frequency

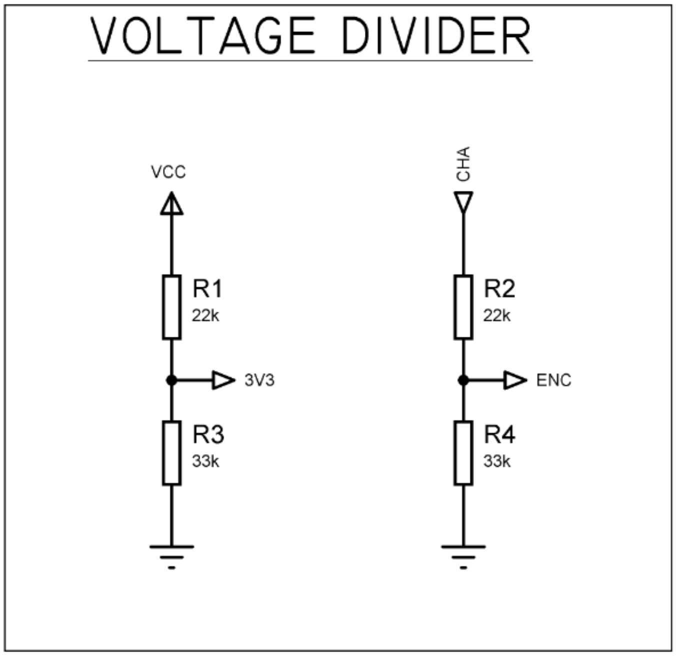

Fig. 4. Voltage Divider Schematic Diagram.

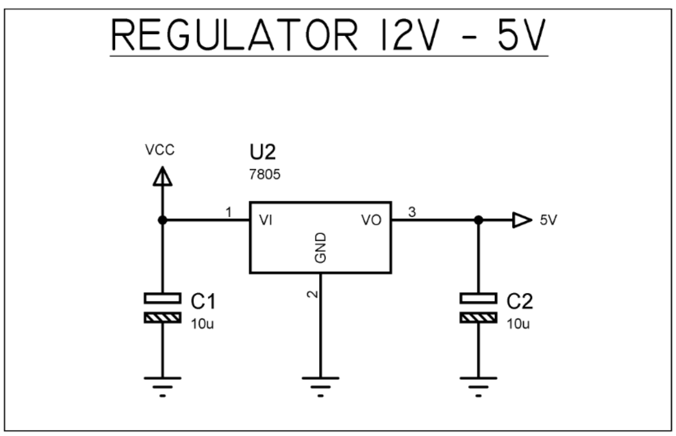

Fig. 5. Regulator Schematic Diagram.

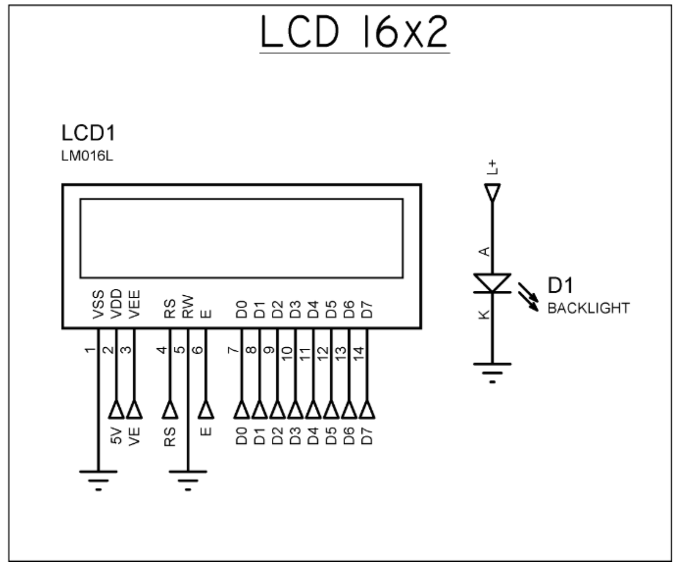

Fig. 6. LCD Schematic diagram

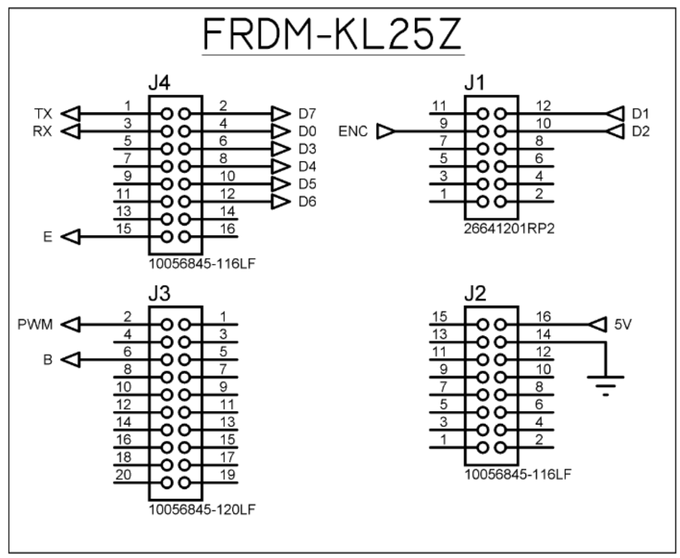

Fig. 7. FRDM-KL25Z4 Schematic Diagram.

and angular speed of the motor and returning a beep indicating that the system is in operation

- VC: Turn off the system.
- VPxxx: Sets the speed from the value ”xxx”, which must be between the values 0 and 100 which indicates the % of desired PWM for the motor)

In case of error, the system returns through the Bluetooth module the message ”ERR”; in case of success, the system returns the message ”ACK”. We used the BlueTerm application for Android as interface, but as future steps, we want to replace these commands for a more friendly interface. We used PWM control of speed to the motor. The PWM is connected to an H-bridge IC that has the function of power drive to the motor.

For speed acquisition, we used the motor encoder itself, with one of its channels connected to a plate as shown in the figures of the previous section. The necessary functions for the communication of the obtained data to the LCD display station are attached in the file ”LCD_hal.c”.

The circuit of the buzzer is the simplest. The buzzer is turned on and off, keeping 1 [ms] in each state for a second. Its implementation can be found in the files ”buzzer_hal” and ”tradutorUart”, as we see in the traceability matrix.

V. Problems and solutions

A. IDE Kinetis installation

The first trouble with the project was the Kinetis IDE installation, once we tried to work with macOS X operational system. Nevertheless, the used debbuger indicated by Prof. Denis was not available for this operational system, and according to the Kinetis Design Studio's installation guide, the only option for macOS is the "Segger" debugger. At this moment we decided to move on Windows operational system in order to solve that problem.

On Windows platform we had also some problems with the installation. After KDS installation the option "Kinetis SDK 1.x project" was not available on "File → New" tab. The solution for this problem is the installation of the newest version of KDS software (version 3.2.0) instead of KDS version 3.0.0.

B. LCD Display

With the LCD display we had some difficulties to actuate on it, and after testing the code on the boards available in the laboratory at UNICAMP we realized that the code is made well. After some problems with the initially LCD installed (which was broken), we have installed a second one, which displays the angular velocity of the motor correctly.

C. Bluetooth Module

In the beginning the Bluetooth module was not very stable, and it was hard to have a connection between the Android system and the Bluetooth module for more than some seconds. We studied some possible answers for this scenario, which bring us to the problem with the stability of the voltage supply source. Therefore a regulator 12 [V] - 5 [V] was connected to the circuit in order to supply the Bluetooth, fixing the problem.

D. Motor Results

When acting on the motor by PWM, we figured out that the motor angular velocity was not linear concerning the PWM duty cycle. We currently investigate 2 hypothesis for this problem : first, that the used H-Bridge (L293D) [8] may have a switching frequency lower than the PWM one. Second, that the motor output may be not linear.

VI. Future Project Steps

Since Femto is a big project, it continues to be developed in order to apply some improvements to it. The next steps for the project are:

- Substitution of the Bluetooth module for WiFi module and integration with a camera system that would allow the experiment to be monitored from any place with internet connection. To do this improvement in the system, it will also be necessary to implement a server and a GUI for computer and/or mobile.
- Limit system to detect when the roll of titanium target tape reaches the end and engine inversion routine implementation. The first hypothesis is that this detection will be done through an optic sensor.
- Refine tape's speed control and mechanical tension control through PID controllers.

VII. Conclusion

We had the opportunity to work on a project with direct application to the scientific production of UNICAMP, improving the interface and security satisfactorily. Besides, we were able to considerably cheapen the equipment, bringing gains for the laboratory research.

Besides, we noted how the relevant modeling systems are to a project, since we could easily reuse functions and codes of laboratories activities. In engineering, this flexibility afforded by a good modeling allows us to save efforts and money, besides the ease of maintenance.

Appendix A
Board Layout

Below is the layout of the board that will be made for implementing in the Femto containing entries for the used peripherals and microcontroller.

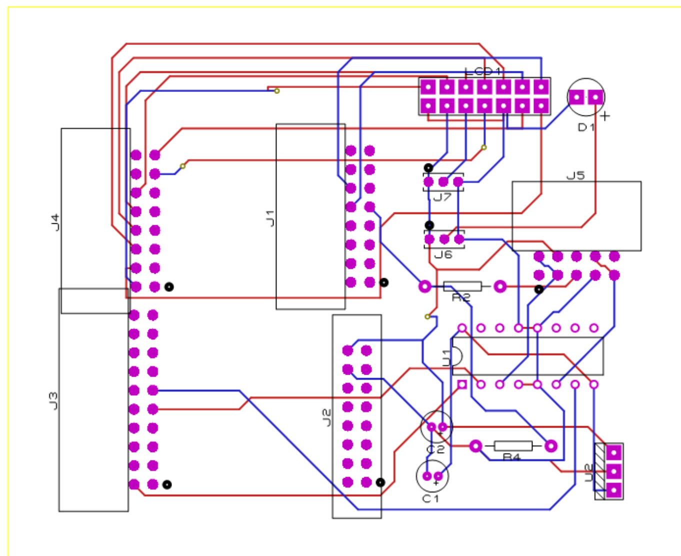

Fig. 8. Created Board Layout Schematic Diagram.

Acknowledgment

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[4] FAULHABER DC-Micromotor Serie 2230 024 S.

[5] MERCURY C-863 DC CONTROLLER - PI.

[6] NXP Semiconductors - Kinetis Design Studio Integrated Development Environment (IDE).

[7] IBM Rational Rhapsody Modeler 7.5.

[8] L293D QUADRUPLE HALF-H DRIVERS - Texas Instruments.

[9] BLUETOOTH MODULE RS232 HC-05.

[10] BLUETERM App for Android - pymasde.es.