An Educational Platform for Teaching Applied Embedded Systems in Distributed Industrial Automation

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This paper describes an educational system demonstrating the use of conventional devices and consumer-grade embedded systems for distributed industrial automation applications.

Modern industrial PLCs use remote I/O units to gather and deliver information for the monitoring and control of industrial processes. These distributed remote units are usually interconnected to the central PLC using an industrial communications network [1]. Nowadays there is some convergence towards the use of Ethernet with supporting protocols such as Profinet, Ethercat, Ethernet/IP, Modbus/TCP, among others [2].

On the one hand, both central units, implemented through industrial PLCs, and I/O modules, have been mostly available from very well established manufacturers, mainly due to demanding regulations and high standard requirements in most fields of industrial automated processes [3,4].

On the other hand, a new generation of embedded systems with very high processing capabilities and at low cost, make it possible and very attractive to consider their use in substitution of the more conventional established-brand PLCs and I/O modules, especially when dealing with applications for less regulated environments. Some examples of successful deployments are those based on the Arduino, such as the Controllino PLC, the M-Duino and the Iono Arduino, as well as those based on the RaspberryPi computer such as the Iono Pi and the UniPi [5,6].

The developed educational system consists of a Central Control Unit that can be either a Siemens S7-1200 PLC, a ARM Cortex M3/4 Board with embedded communications peripherals, or a RaspberryPi very small form factor single-board computer, including communications hardware. For the Remote I/O Module a Vipa 053-1MT00-IM053 Interface Modbus/TCP Slave [7] or a Arduino Uno Board with an Ethernet Shield can be selected. Any combination of central unit and extension module can be used while communications are implemented through the ModBus/TCP protocol at a speed of 100 Mbps.

The ARM-based central unit firmware uses a three-task RTOS implementing the control algorithm, the Ethernet communications and the CAN communications bus. The S7-1200 PLC is programmed in Ladder to achieve the same control and communications objectives. The RaspberryPi-based board is programmed in C and makes use of an updated Xenomai framework implementing two processes: control and communications.

To exemplify and demonstrate the operation of the system, hardware setup and software modules were developed to implement the control of a remote automatic gate.

In the following figures we graphically illustrate the described system. In Figure 1, two possible associations of Central Control Unit and Remote I/O Module are presented. Figure 2 presents two photos of the system hardware implementation for the two specific sets of modules shown in Figure 1. In Figure 3 and in Figure 4 we present two examples of tests showing the action of opening the gate. The test in Figure 3 refers to the Arduino (Remote I/O)/ARM Central Control Unit association while the test in Figure 4 refers to the Arduino (Remote I/O)/S7-1200 Control Unit association.

Figure 1. Example associations - Left: Arduino and S7-1200. Right: Arduino and ARM platform.

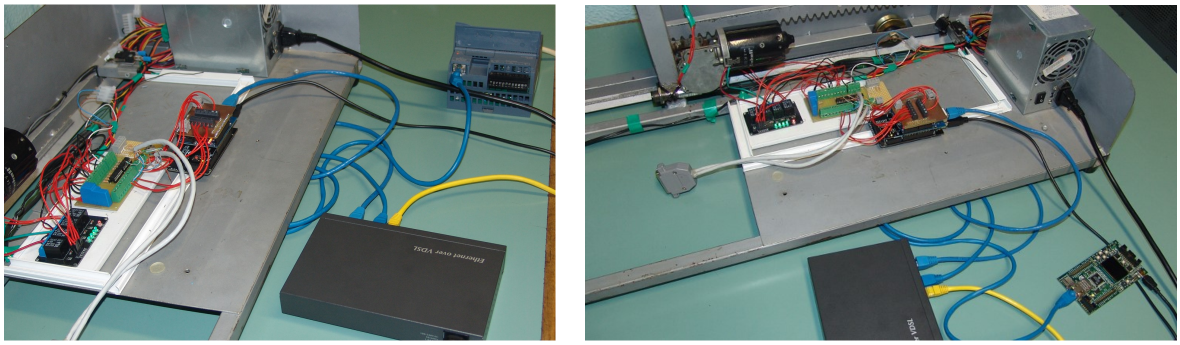

Figure 2. Hardware implementation - Left: Arduino and S7-1200. Right: Arduino and ARM platform.

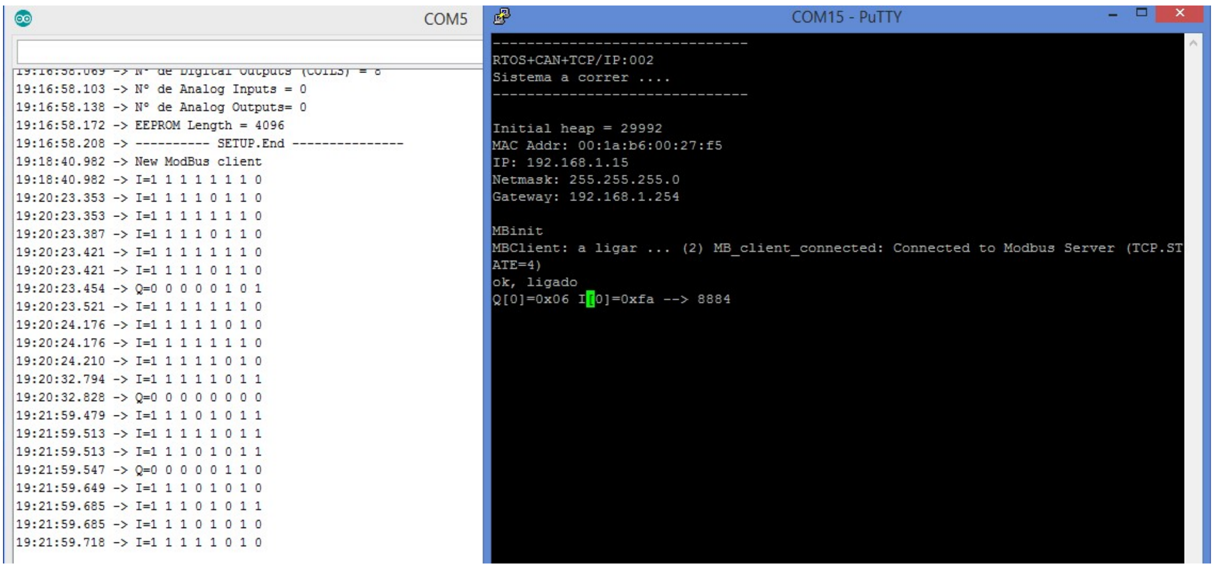

Figure 3. Test - Left: Arduino (Remote I/O), Right: ARM (control algorithm in C, when door is open).

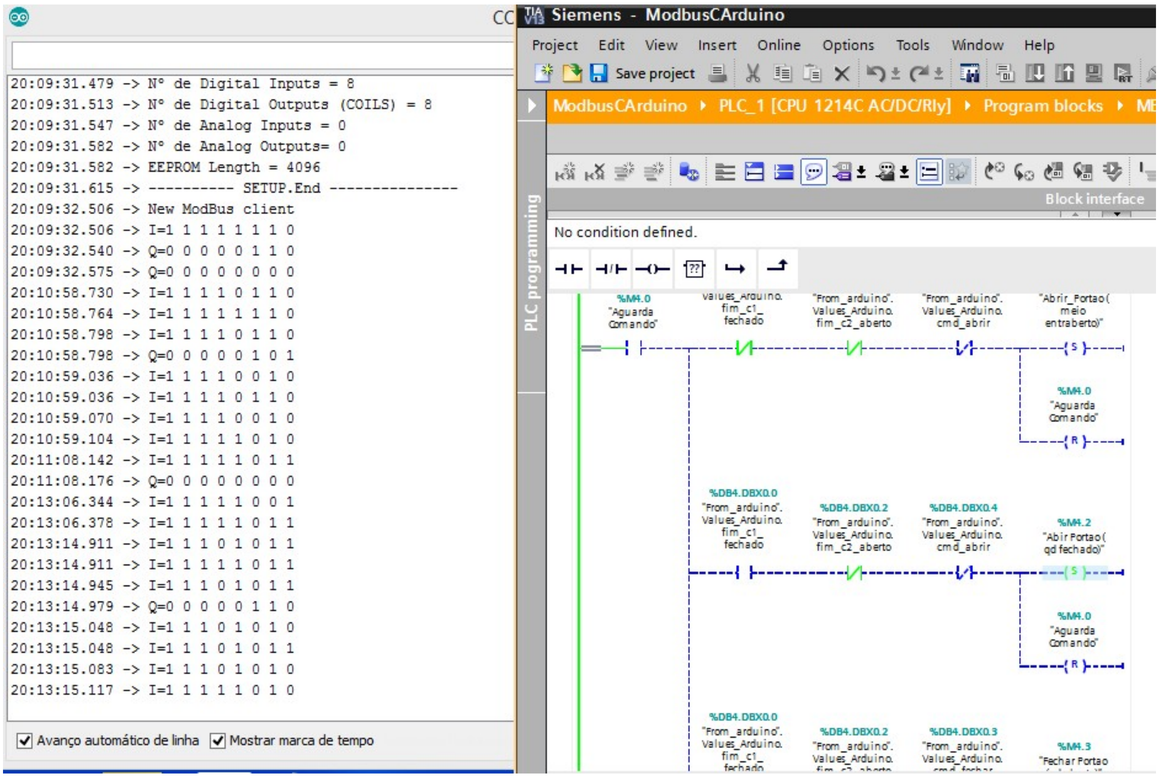

Figure 4. Test - Left: Arduino (Remote I/O), Right: S7-1200 (control algorithm in Ladder, when door is open).

This experimental setup allows electrical engineering students to develop skills on applied embedded systems, industrial communications and real-time operating systems. This includes both conventional manufacturer devices, as well as new high performance embedded systems through easily available development boards.

The conventional hardware modules can be exchanged for other manufacturers with similar characteristics, while different general use embedded systems can also be integrated, with added hardware configurations and programming efforts.

The software modules can be edited and extended to modify the system sensing and control behavior. Furthermore, communication failures can be injected to test and improve failure robustness, as well as to develop the student's awareness for functional safety aspects in industrial automation systems and to identify specific situations that may require the use of SafetyPLCs.

Keywords— Embedded Systems, Industrial Automation, Distributed Control, Education

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