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Research Article

Low-Cost MATLAB-Simulink Compatible Data Acquisition Card Hardware and Software Design for Control and Test Applications

Furkan Perçin[1*], Savaş Şahin[2], Alkım Gökçen[3]

[1] İzmir Katip Çelebi University, Faculty of Engineering and Architecture, Departmant of Electrical Electronics Engineering, İzmir, Turkey (ORCID: 0000-0003-4624-1443), percinfurkan1999@gmail.com

[2] İzmir Katip Çelebi University, Faculty of Engineering and Architecture, Departmant of Electrical Electronics Engineering, İzmir, Turkey (ORCID: 0000-0003-2065-6907), sahin.savas@yahoo.com

[3] Baylan Ölçü Aletleri Sanayi ve Ticaret LTD. ŞT İ. Department of Research and Development, İzmir, Türkiye (ORCID: 0000-0002-8131-388X), a.gokcen@baylanwatermeters.com

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Abstract

This paper presents a general-purpose data acquisition system is designed for control and test applications. In this data acquisition system, the connections of the input-output ports and peripherals are performed by employing the STM32L4 microcontroller with ARM-Cortex M4 architecture. The microcontroller communicates with the MATLAB-Simulink, transmits given commands to peripheral units, and receives data from the environment. The system has four digital input-output, two analog inputs, two analog outputs, four pulse width modulation outputs, an L298 driver, and encoder inputs. The connections of the peripherals with the microcontroller are transferred to the printed circuit board in the Altium Designer program to perform real-world applications and test. Universal Serial Bus (USB) is used to maintain communication between Simulink library and controller. This communication process provides not only the control of input-output, sensors and driver ports but also opportunity of transfer the process of sampled data. The library created in the MATLAB-Simulink environment interprets and observes the system's data and controls the peripherals. This library contains blocks to control the overall system and each input-output. Proposed system is intended to be low-cost, accurate, reliable, high resolution, and compatible with various environments that may communicate over the USB port.

Keywords: DAQ, Data Acquisition, STM32, MATLAB-Simulink, USB

Kontrol ve Test Uygulamaları için Düşük Maliyetli MATLAB-Simulink Uyumlu Veri Toplama Kartı Donanımı ve Yazılımı Tasarımı

Öz

Bu makale, kontrol ve test uygulamaları için tasarlanmış genel amaçlı bir veri toplama sistemi sunmaktadır. Bu veri toplama sisteminde giriş-çıkış portları ve çevre birimlerinin bağlantıları ARM-Cortex M4 mimarisine sahip STM32L4 mikroişlemci kullanılarak yapılmaktadır. Mikrodenetleyici, MATLAB-Simulink ile haberleşir, verilen komutları çevre birimlerine iletir ve ortamdan veri alır. Sistemde dört dijital giriş-çıkış, iki analog giriş, iki analog çıkış, dört darbe genişlik modülasyonu çıkışı, bir L298 sürücüsü ve enkoder girişleri bulunur. Çevre birimlerinin mikroişlemci ile bağlantıları, gerçek dünya uygulamalarını gerçekleştirmek ve test etmek için Altium Designer programında baskılı devre kartına aktarılır. Evrensel Seri Veri Yolu (USB), Simulink kütüphanesi ve işlemci arasındaki iletişimi sürdürmek için kullanılır. Bu iletişim süreci, yalnızca giriş-çıkışlar, sensörler ve sürücü portlarının kontrolünü sağlamakla kalmaz, aynı zamanda örneklenen verilerin sürecini aktarma olanağı da sağlar. MATLAB-Simulink ortamında oluşturulan kütüphane,

* Corresponding Author: percinfurkan1999@gmail.com

sistem verilerini yorumlar, gözlemler ve çevre birimlerini kontrol eder. Bu kitaplık, tüm sistemi ve her bir girdi-çıktıyı kontrol etmek için bloklar içerir. Önerilen sistemin düşük maliyetli, doğru, güvenilir, yüksek çözünürlüklü ve USB bağlantı noktası üzerinden iletişim kurabilen çeşitli ortamlarla uyumlu olması amaçlanmıştır.

Anahtar Kelimeler: DAQ,Veri Toplama, STM32, MATLAB-Simulink,USB

1. Introduction

Data acquisition (DAQ) is the process of sensing and measuring the physical or electrical phenomenon and converting the data into a digital form to accomplish meaningful information by computer programs. In general, a DAQ system is a combination of software, hardware, and a computer program to process acquired data. (Hercog & Gergič, 2014). This system helps to obtain specific information about the environmental parameters(variables) from the acquired data by capturing, measuring, and analyzing the characteristics of the data (Rezk, Tyukhov, Al-Dhaifallah, & Tikhonov, 2017). This specific information must be obtained accurately, with high resolution and precision (Dipova & Mathematics, 2017). Therefore, DAQ systems are evaluated within the scope of peripherals, sampling of signals from sensors, controlling actuators, sampling rate, communication type, resolution, functionality, and cost (Robson & Bousselham, 2006).

DAQ systems have many usage areas such as industry, academic usage, environmental monitoring, power plants, and healthcare (Abdallah & Elkeelany, 2009). Computer-based data acquisition systems used in mentioned fields have traditionally required the installation of complex and expensive hardware (Ocaya, 2005). These computer-based DAQ systems have the other disadvantages of cumbersomeness, high power consumption, and require design redundancy. In real-time systems, powerful and flexible software should be used to data acquisition, measure, and manipulation of data appropriately (Gani & Salami, 2002). MATLAB-Simulink is a graphical programming language that provides an environment suitable for doing compatible work with the DAQ system as an application area. Khan et al. employed an FPGA (Field Programmable Gate Array) based DAQ card with a PCI Express (Peripheral Component Interconnect Express) communication protocol. PCI Express card has an eight 10-bit ADC and DAC, one digital IO and four PWM outputs (Khan, Hafeez, Mirza, & Ain, 2011). Ocaya performed a PIC16f877 microcontroller-based DAQ system that serially communicates with the computer by RS232 standard (Ocaya, 2005). Kanani and Thakker designed a low-cost DAQ system based on an Arduino-Uno board. LabVIEW GUI environment was used to control and monitor the proposed system. The VISA tool in LabVIEW communicates with the system connected to the computer via USB. The created system has been tested over a scenario (Kanani & Thakker, 2015). Hence, there is a need to provide a low-cost, compact size, low power consumption, and high-resolution device with a software library suitable for control and testing operations.

The proposed system's software and hardware design procedures, a 32-bit ARM microcontroller-based MATLAB-Simulink compatible DAQ card, were performed. The microcontroller at the system's center realizes data acquisition, functional filtering, and communication tasks. The microcontroller's communication rate with the computer takes place at 9600 bps. The data acquired by the microcontroller is transferred to the computer with the Universal Serial Bus (USB) serial communication method. A Simulink library is created in order to be able to operate on data taken from sensors and to control actuators. The configurations of software and hardware of the proposed system are presented, and the performance of the proposed system is tested.

The paper is organized as follows: In Section 2, the hardware and software design of the overall DAQ system is presented. Section 3 shows the results, and Section 4 gives the conclusions and recommendations of the work.

2. Material and Method

This section introduces the peripherals of DAQ systems as follows: Digital inputs, encoder inputs, and Analog-Digital Converter (ADC) for reading the environmental parameters; Digital outputs, Pulse Width Modulation (PWM) outputs, Digital-Analog Converter (DAC), and L298 driver to adjust signals for actuators. Also a library, which is created in the MATLAB-Simulink environment, provides the interpretation and processing of the data. The flowchart of the proposed system for control and test applications is in given Figure 1.

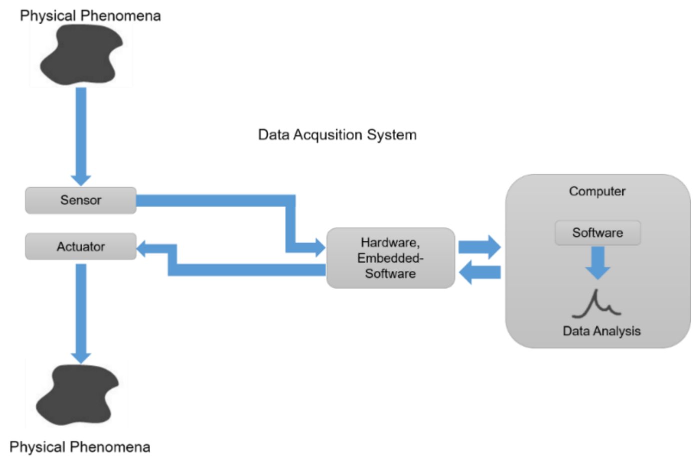


Figure 1. Data acquisition system flowchart

2.1. Design of Data Acquisition Card

The STM32 platform with 32-bit ARM technology, dominantly used in embedded systems, is used as a microcontroller. The reason is that it is high-precision, high-frequency, high-reliability, comprehensive architecture, and portable (Zhang & Kang, 2013). STM32L476 (Figure 2) is used as the microcontroller in the proposed system. STM32L476 has 128 kB Flash and up to 80 MHz frequency with ARM Cortex M4 core. The microcontroller is responsible for acquiring data, transmitting given commands to peripheral units, and communication. The USB serial interface provides communication between the microcontroller and MATLAB-Simulink.

Figure 2. STM32L476 with ARM-Cortex M4

Various inputs-outputs (IOs) are needed for the microcontroller to connect with the outside world. While the inputs provide the signal or data to be evaluated by the system, the outputs control the signal or data sent from the system to another system or circuit component (Braudaway & measurement, 2006). There are four digital inputs to check the status of the peripheral connected to the DAQ card. When the microcontroller's digital input is active, it creates an interrupt request and transmits the necessary information to MATLAB-Simulink. Two-channel ADC has been added to provide data reception from peripheral units producing analog output. The ADC will take the analog signals obtained from the peripherals producing analog output and convert those signals into a digital signal that the computer can use, and will make the data to be used in operations easy to be processed with high resolution and precise results. The proposed system has a 12-bit resolution ADC with a 4096 step. Encoder inputs have been added to determine the rotating actuators' speed and direction. The encoder has two out-of-phase output channels, channel A and channel B. The phase relationship between the channels is considered to determine the direction of motion. Thus, the direction of motion is detected, whether clockwise or counterclockwise. For the rotation speed, revolution per minute (RPM) is found by counting the pulse produced by the encoder at each rising or falling edge. Adding all input configurations to the system will ensure that the requirements are met in the best possible way.

The DAC generates an analog voltage in response to the numerical values set by the controller. Two DAC channels have been added to the card to control peripheral units that need to be controlled analogously. Resolutions of channels are configured as 8-bit. DAC can be used in dual mode when synchronous update operations are required. In order to control the peripherals that need to be controlled digitally, four-channel digital outputs are created in the system. PWM is used to control analog peripherals by generating an analog signal using the system's digital output. The main components of PWM output are duty cycle and frequency. Duty cycle is defined as the percentage of the signal's total time in a high state. Frequency defines how many times PWM repeats per unit time (Kim & Sul, 1995). The card has four PWM outputs. PWM frequency is adjustable between 50Hz to 50kHz, and the duty cycle can be changed from 0 to 100 percent. L298 driver is embedded in the DAQ card for test and control applications. This dual full-bridge driver can support up to 24 volts as input voltage and 46 volts at the output.

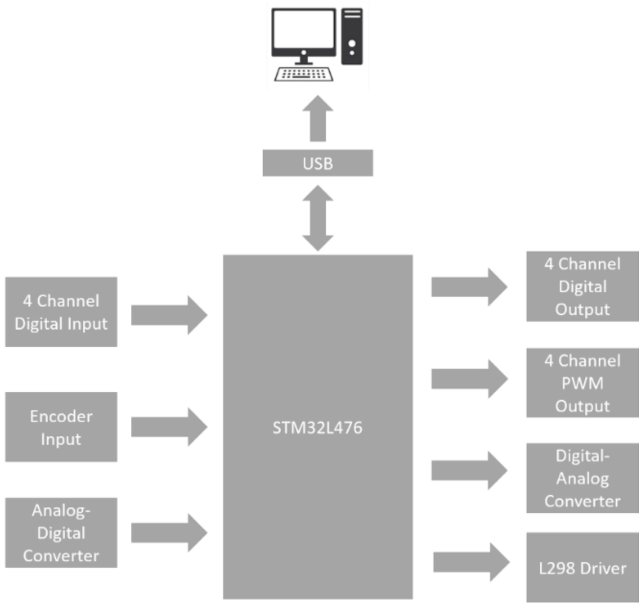
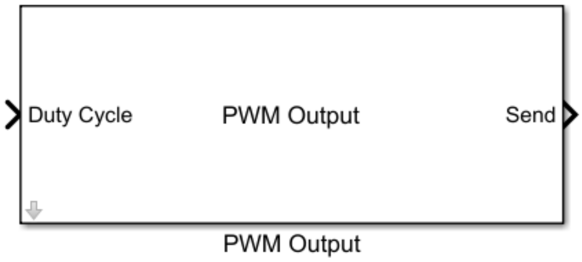


Figure 3. Block Diagram of DAQ System

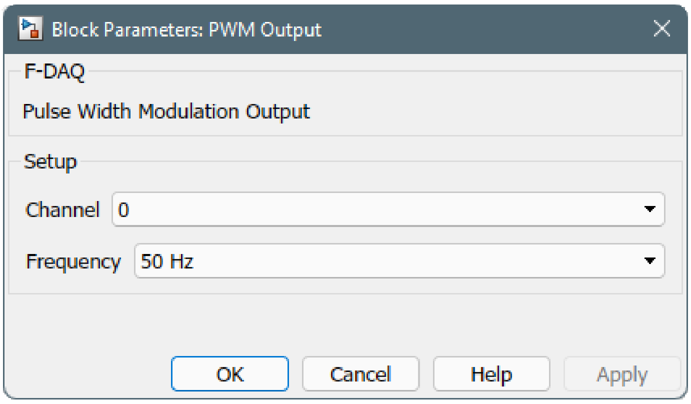
2.2. Design Phase of Simulink Library

MATLAB-Simulink is an environment with the graphical language used for data acquisition, peripheral control and industrial purposes (Kos, Kosar, & Mernik, 2012). A library was created in the MATLAB-Simulink environment in the designed work by communicating with the DAQ card through the serial communication interface for the control of the card and the sample of the data is provided. The Instrument Control Toolbox, available in Simulink, is used to communicate with the card.

Simulink library consists of 8 blocks to monitor and control the DAQ card. These blocks; are system setup, digital output, PWM output, DAC output, digital input, ADC input, encoder input, and L298 driver. System function (s-function) arbitrates the working principle of the blocks during the different times of the simulation like initialization, outputs, and termination. The necessary parameter options for the block are presented by applying a mask to the blocks created with the S-function. The System Setup block is the main Simulink block. It implements the selection of inputs and/or outputs to be used in the hardware part of the system. The Digital Output block provides control of the use of the digital outputs on the DAQ card. The desired channel to be used can be selected from the block's settings. By default, channel 1 is spotted. The digital output on the card depends on the input value of the Digital Output block. The Digital Input block gives output depending on whether the microcontroller's digital input is high or low. The channel to be used is selected from the block parameters window. ADC Input block gives output to observe the value read from the analog peripheral connected to the card. Channel selection can be made for ADC inputs. The DAC Output block generates analog output from the hardware in response to the value connected to its input. On the other hand, the Encoder Input block outputs the data provided by the encoder sensor connected to the card. Each sensor pulse triggers an interrupt in the microcontroller, and the data is transferred to the Simulink. The L298 Driver block controls the peripheral unit connected to the L298 IC. It provides control of 4 digital outputs on the DAQ card. 2 DC motors or 1 stepper motor can be driven simultaneously. The PWM Output block (Figure 4 (a)) is designed to modify the PWM signal with 4 channels. The frequency of the PWM signal can be selected from the block's parameter screen (Figure 4 (b)) between 50 Hz and 50 kHz. The value connected to the input of the block evaluates the duty cycle percentage.



(a)



(b)

Figure 4. PWM Output block (a) and Block Parameters window (b)

2.3. Communication

DAQ card communicates with MATLAB-Simulink via Transistor-Transistor Logic(TTL) communication over USB serial communication protocol. The preference for USB is due to its ease of use, speed, reliability, low energy consumption, and cost. 2 USB ports are integrated into the DAQ card (Figure 5). The first of the ports is connected to the USB OTG pins of the microcontroller. The second port is designed to communicate over UART. The CH340, inserted to the DAQ board, realizes the UART to the TTL interface. 9600 bps is used as the communication rate. The studies were carried out via the second USB port in the proposed project. Data packets called telegrams are created to transfer data securely. Thus, the communication between MATLAB-Simulink and the hardware is provided without problems.

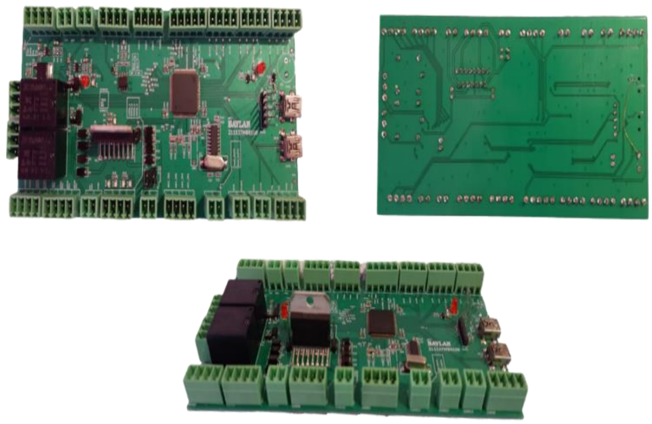


Figure 5. DAQ card from different views

3. Results and Discussion

Different scenarios were applied to test the designed DAQ card's functionality and the Simulink library's operability. One of these scenarios tests the ADC inputs and PWM outputs with the related blocks in the MATLAB-Simulink. The rotation speed of the DC motor, connected to the L298 driver on the board, is adjusted with PWM according to the temperature value evaluated from the ADC. The LM35 temperature sensor was used to measure the ambient temperature. The voltage value sent by the sensor to the controller was read through the ADC Input block in the Simulink library. The reading is between 0 and 3.6 V. Eq1 was used to obtain the temperature value. The sensor value increases or decreases by 10 mV with each degree change.

$$Temperature = \frac{(ADC_{value} \, / \, 4095) * 3600.0}{10.0}$$

(Eq1)

Serial Configuration, Serial Send, and Serial Receive blocks from the Instrument Control Toolbox, a built-in library, were used to communicate between MATLAB-Simulink and DAQ card. These blocks are ready to use by setting baud rate, communication port, parity bit, and data bits parameters. In the System Setup block, it is stated that the ADC Input, L298 Driver block, and PWM Output blocks will be used in the test scenario. Channels used for ADC Input and PWM output blocks are selected. The pins of the L298 driver are set to drive the motor and determine the direction. 10 kHz was chosen as the frequency value of the PWM signal. The MATLAB Function block was used to determine the duty cycle value of the PWM signal generated against changing temperature values. This block determined the duty cycle to adjust the motor's speed for temperature values in particular ranges. The output of the selected PWM channel is connected to the corresponding input of the L298 driver. Figure 6 shows the PWM Output signal graph and Figure 7 shows the temperature data taken from the LM35. The simulation and test results confirmed the operation of the system. With these simulations and tests, it has been confirmed that all the system features are achieved.

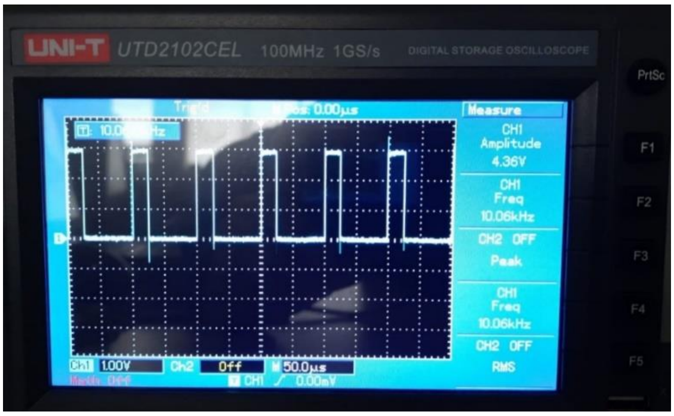


Figure 6. 10kHz PWM signal with a %25 duty cycle

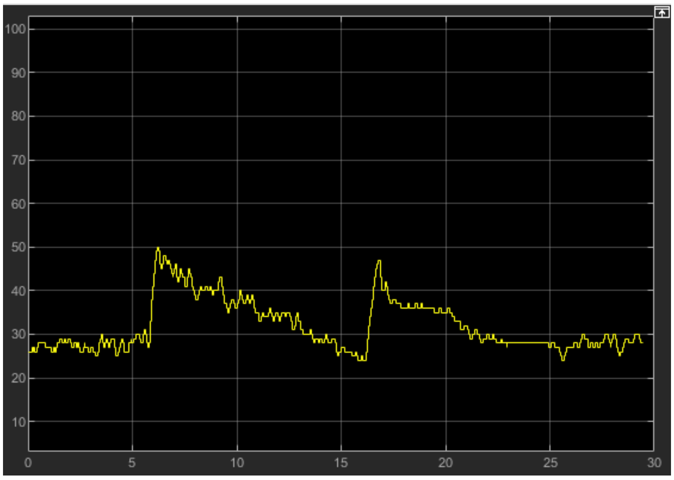


Figure 7. LM35 temperature sensor plot

4. Conclusions and Recommendations

This paper aims to present a general-purpose DAQ system for real-time data exchange with the MATLAB-Simulink environment. The communication of the manufactured DAQ card with the computer was provided by TTL communication over USB serial communication method. Thus, it was guaranteed that the data could be transferred quickly and securely. ADC, DAC, encoder, PWM, digital IOs, and L298 driver are integrated into the system to meet the requirements best. Due to the blocks in the library created in the MATLAB-Simulink environment, data from the relevant peripherals can be interpreted and sampled, and actuators can be controlled. The purchase of existing DAQ systems or the solution of any problem in these devices are enormous costs that individual users cannot afford and require large budget allocations for companies. For this reason, a low-cost, high-resolution system that can be used with the desired solver in the MATLAB-Simulink environment has been successfully implemented. The performed system has been tested, and the results have been presented. Machine learning algorithms can be applied for future works by creating a data set from the obtained data.

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