DC Motor Modelling Using Bluetooth Wireless Technology

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Abstract: This paper presents the modelling of a DC motor through empirical identification method using wireless technology communication such as Bluetooth. The Bluetooth module is connected to a microcontroller which sends data regarding the speed of the motor to a MATLAB interface. Based on the data, the DC motor is modelled and simulated within MATLAB/Simulink.

Keywords: DC motor modelling, empirical identification, MATLAB/Simulink simulation

1. INTRODUCTION

In the last decades, industrial applications have been developed considerably which led to the development of appropriate complex autonomous control systems. Control is usually done using different types of microcontrollers which share information between them via multiple buses.

The major impediment in achieving a qualitative management of these complex industrial applications is represented by the impossibility to obtain using analytical methods a perfect dynamic or stationary model. That is why in most cases the system is treated as a black-box.

One way to model a black-box system is to use the empirical identification which is based on input-output data obtained from measurements. Usually, in embedded control systems, the microcontroller unit does these measurements which can be afterwards transferred using different communication protocols such as Ethernet, CAN, USB, SPI, UART, etc. The UART bus is used to interface a microcontroller to a Bluetooth module. Bluetooth is a wireless technology standard for exchanging data using short-wavelength radio waves from fixed and mobile devices.

After acquiring the data from the measurements, based on the complexity of the information, the data is processed, filtered and mathematical instrumentation is used with the purpose to obtain the model of the system. Once the model is defined, it can be used within simulations to determine the most efficient control algorithm.

Based on these topics, the paper is structured as follows: Section 2 briefly presents relevant related studies. Section 3 provides a short overview of the hardware and software tools used for modelling the DC motor. Section 4 presents the Bluetooth wireless technology standard and the UART communication. Section 5 presents the DC motor modelling and simulation with MATLAB/Simulink. Section 6 presents the conclusions of the paper.

2. RELATED STUDIES

C. Bisdikian (2001) from IBM Corporation studied the Bluetooth wireless technology. This industry standard started to be developed in 1998 when Ericsson, IBM, Intel, Nokia and Toshiba formed the Bluetooth Special Industry Group (SIG) with the purpose to obtain a global solution for short-range wireless communication operating in the unlicensed 2.4 GHz ISM (industrial, scientific, medical) band.

In March 1999, the IEEE 802.15 standards working group was created in order to develop a family of communication standards for wireless personal area networks (WPANs).

Vijantth S.A. and Musab J.O.E. (2009) studied the wireless system identification. Their research looked into the concepts of system identification and the behavior of the identifier components when placing wireless links between the system and the identifier. They studied the possibility of performing system identification over wireless network for online linear process system.

Many studies include the identification of thermal models for domestic buildings based on temperature data obtained. C.A. Carmody and T. O'Mahony (2009) studied the system identification using a wireless sensor network to measure actual temperature variations. The data obtained was used to identify a process model using MATLAB System Identification Toolbox. A. Caracas et al. (2012) launched a special-purpose wireless sensor network designed to collect high-quality data of the building's indoor and outdoor climate, heating system and energy consumption. The sensor data was analyzed in order to identify the building's potential to act as a flexible energy consumer.

Collecting a richer set of sensor data is very important to improve the accuracy of the models. This leads in more precise and more efficient control.

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3. OVERVIEW

The following hardware and software components have been used to model the DC motor, which can be seen in Fig. 1 and in Fig. 2:

- Development platform FRDM-KL25Z from NXP containing the microcontroller unit MKL25Z128VLK4. The platform was used to actuate the DC motor and to acquire the data from the measurements. Afterwards the data was transmitted using Bluetooth technology towards a MATLAB/Simulink interface. The input is represented by the electric voltage command applied on the DC motor and the output is represented by the rotation speed of the DC motor calculated in m/sec.

- FRDM-TFC NXP Cup Shield containing the H-Bridge.

- Standard DC motor RN260C with winding 18130.

- Unipolar digital position Hall-effect sensors, Honeywell SS449a, used as an encoder to calculate the rotation speed of the DC motor.

- Bluetooth module RN52 used for receiving and transmitting data through the MATLAB interface towards the microcontroller.

- MATLAB/Simulink interface which implements a Graphical User Interface (GUI) and assures the connection to the microcontroller's Bluetooth module.

The software for the microcontroller's drivers needed for modelling of the DC motor was implemented based on the microcontroller's datasheet. The most important drivers are: UART driver for Bluetooth communication, PWM driver for actuating the DC motor, Encoder driver for calculating the rotation speed.
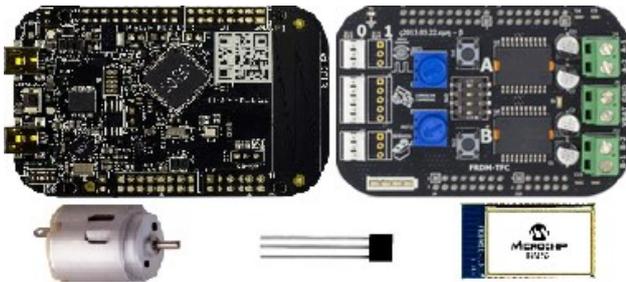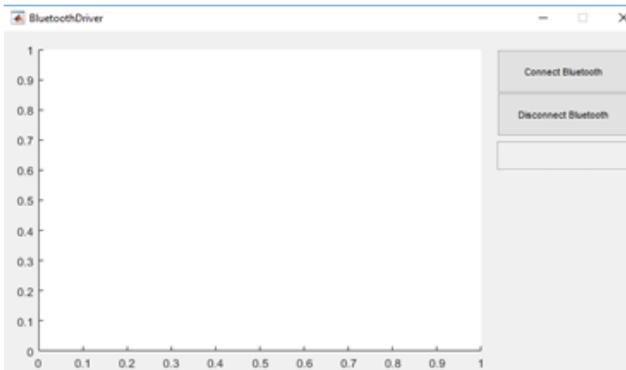

Fig. 1: Hardware components

Fig. 2: MATLAB/Simulink interface

4. BLUETOOTH COMMUNICATION

4.1. Bluetooth technology standard

The IEEE standardized Bluetooth as IEEE 802.15.1 used to create a Wireless Personal Area Network standard based on the Bluetooth Foundation Specification.

Bluetooth is defined as a layer protocol architecture, seen in Fig. 3, which consists of many protocols organized into different layers. The most important layers are:

- Physical Radio Layer which deals with ratio transmission and modulation.

- Baseband Layer has TDD-TDMA (time-division duplex time-division multiple access) channel access method.

- Link Manager establishes connections between devices.

- Logical Link Control and Adaptation Protocol (L2CAP) multiplexes multiple logical connections between two devices.

- Service Discovery Protocol discovers services offered by other devices and their associated parameters. Any Bluetooth device transmits on demand information regarding the device name, device class, list of services and technical information.

- Telephony Control Protocol defines the control signaling to establish calls between Bluetooth devices.

- Radio Frequency Communications generates a virtual serial data stream.

There are different Bluetooth modules which can be used to transfer data. In this paper, Roving Network's RN52 Bluetooth module was used, which combines a class 2 Bluetooth radio with an embedded DSP processor. The block diagram of RN52 can be seen in Fig. 4. The most important features of this module are:

- Fully qualified Bluetooth version 3.0 module.

- Embedded Bluetooth stack profiles.

- Configurable through commands over UART.

- UART, USB, SPI, speaker, microphone interfaces.

- Frequency band: 2.4 ~ 2.48 GHz.

- Maximum data rate: 3 Mbps.

- Supply voltage: 1.8 ~ 3.6 V DC.
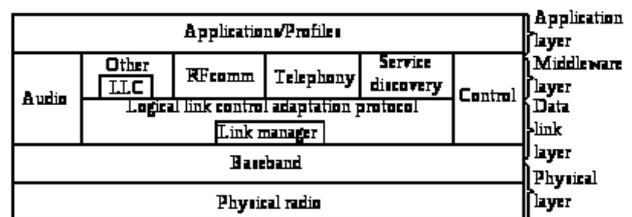
- Operation range: 10 meters.
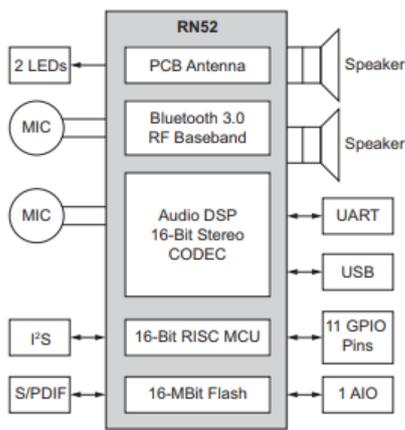

Fig. 3: Bluetooth Protocol Stack

Fig. 4: RN52 Block Diagram (microchip.com)

4.2. UART standard

UART (Universal Asynchronous Receiver-Transmitter) is a device for serial communication in which the data format and transmission speeds are configurable.

UART takes bytes of data and sequentially transmits it as bits. At destination, another UART reassembles the bits into complete bytes. The frame format which is used can be seen in Fig. 5. The frame includes a Start bit, which is a logic low signal, 5-9 bits of data and a parity bit if the data length is not 9 bits. The end of the frame can have one or two stop bits which are logical high signals that allow detection of the end of the transmission.

Fig. 5: UART frame (mikroe.com)

The transmission rate (baud rate) needs to be the same for both the source (transmitter) and the destination (receiver). The baud rate specifies how fast data is sent over the bus and it is specified in bits per second. Standard baud-rates are: 1200, 2400, 4800, 9600, 19200, 38400, 57600 and 115200.

FRDM-KL25Z microcontroller has 3 UART devices which are similar. The main features of these devices are:

- Full-duplex.
- Double-buffered transmitter and receiver.
- Programable baud rates with a 13-bit modulo divider.
- Interrupt-driven or polled operation.
- Hardware parity generation and checking.
- Programmable 8-bit or 9-bit character length.
- Programmable 1-bit or 2-bit stop bits.
- Optional 13-bit break character generation / 11-bit break character detection.
- Selectable transmitter output polarity.

The UART transmitter and receiver block diagrams of the microcontroller FRDM-KL25Z can be seen in Fig. 6 and in Fig. 7 respectively.
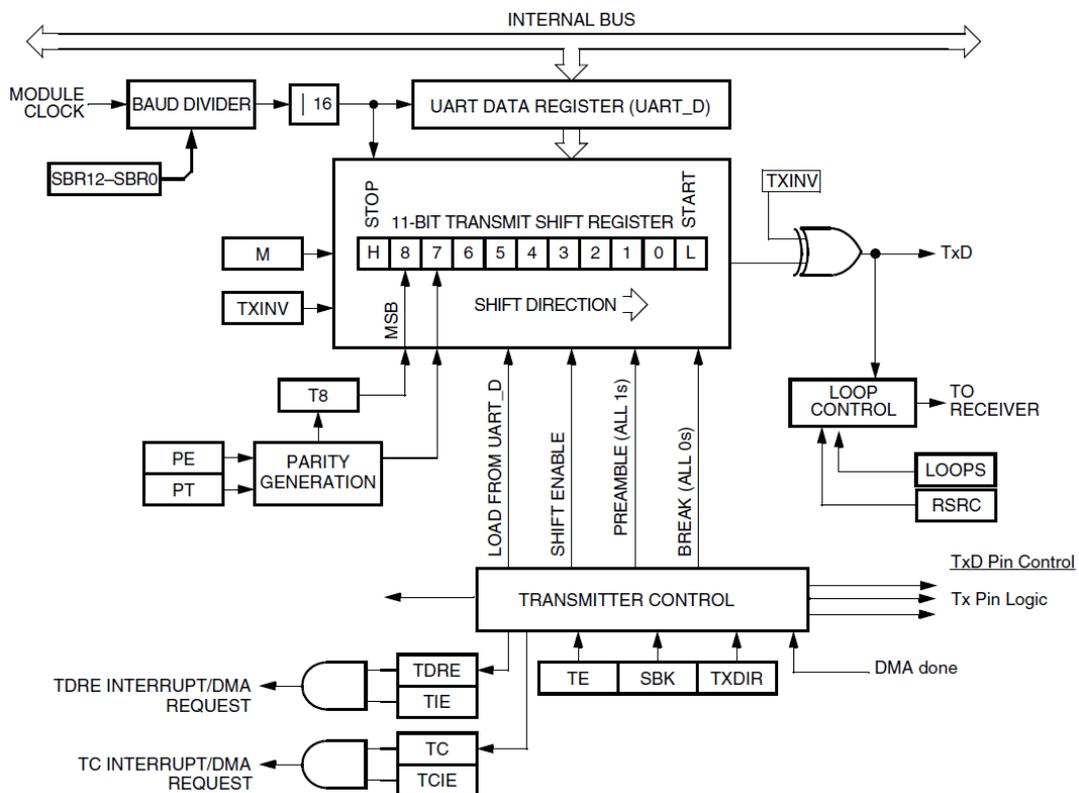

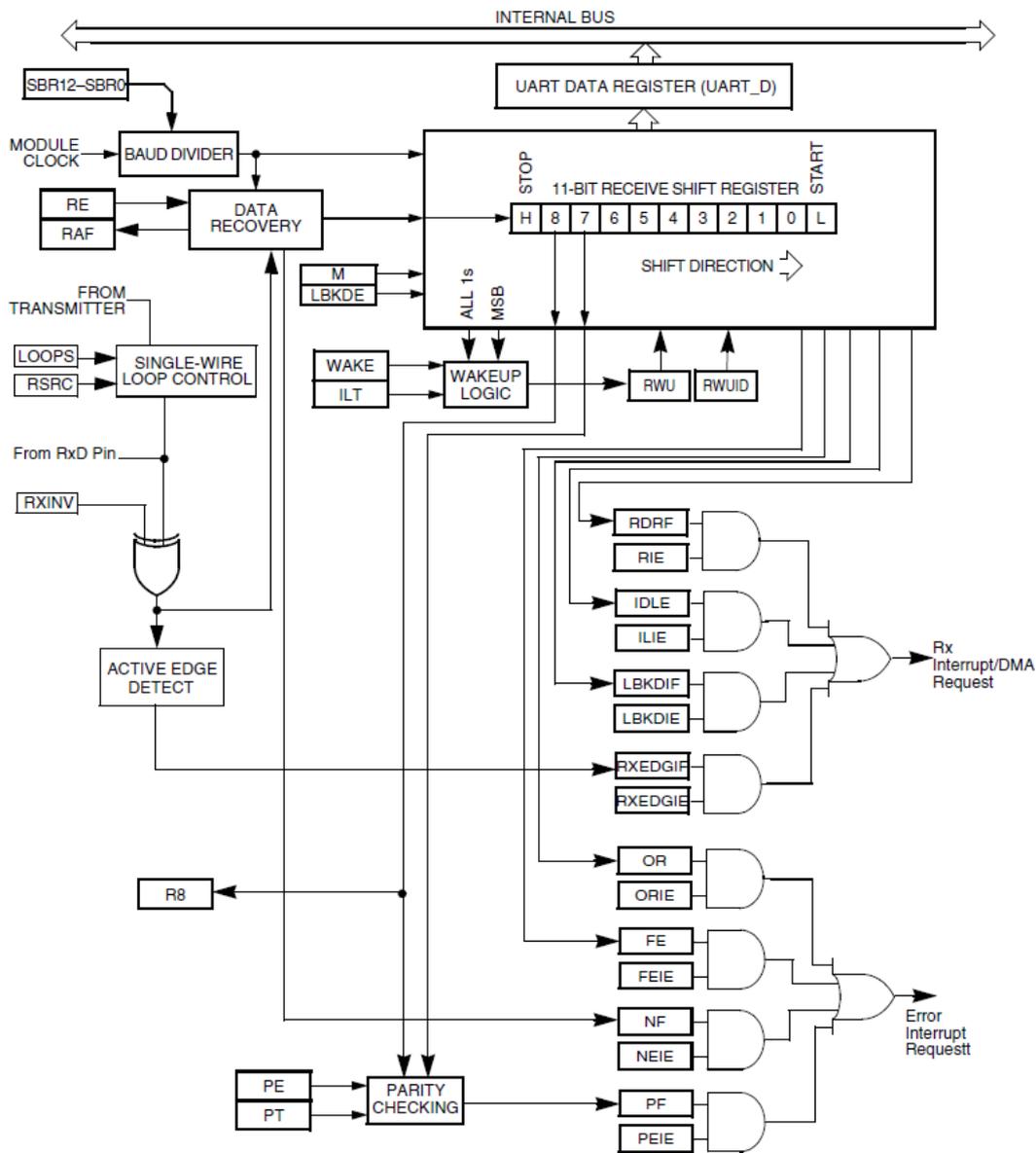Fig. 6: FRDM-KL25Z UART transmitter block diagram (nxp.com)

Fig. 7: FRDM-KL25Z UART receiver block diagram (nxp.com)

5. DC MOTOR MODELLING

5.1. Motor modelling

Black-box systems can be modelled by acquiring the input-output signals data which influence the system. In this case, data acquisition related to the DC motor was done as seen in Fig. 8.
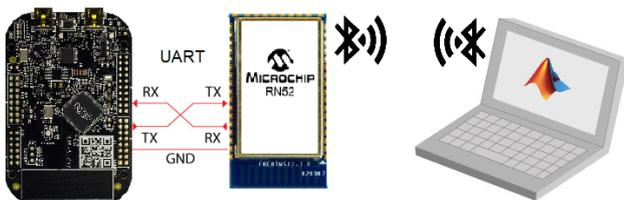

Fig. 8: System communication via Bluetooth

Modelling the DC motor using empirical identification via wireless technology was accomplished by establishing the connection between the RN52 Bluetooth module to the MATLAB/Simulink interface. The Bluetooth module was attached to the microcontroller's UART circuit.

The software was programmed to transmit every 4 msec. towards the MATLAB interface data regarding the DC motor's angular velocity. This velocity was calculated using the Encoder driver which transforms it into linear velocity measured in meters per second.

Input for the DC motor was the voltage applied by the H-Bridge based on the constant duty cycle values of a 1 kHz frequency PWM signal sent by the microcontroller's software. Therefore, the input can be considered a unit step input.

Two different duty cycle values for PWM were enough to determine an approximated dynamical model for the DC motor. The first constant duty cycle value was of 26% which corresponds to about 2 Volts. The second constant duty cycle value was of 39% which corresponds to about 3 Volts. In this way the Heaviside step is simulated, $\Delta u = 1$ Volt. The step response was represented in the MATLAB GUI interface and it can be seen in Fig. 9.

Based on the aspect of the DC motor response, the dynamical model has been approximated with a first order transfer function, in which: K – gain factor, T – time constant, τ – dead-time constant.

$$H(s) = \frac{Y(s)}{U(s)} = \frac{K \cdot e^{-\tau \cdot s}}{T \cdot s + 1} \qquad (1)$$

The parameters for this transfer function have been identified with the experimental identification method based on the response to the Heaviside step used for first order transfer function parameters. The method can be seen in Fig. 10.

The dead-time constant was considered $\tau = 0$ because changing the velocity of the DC motor is a fast process.

The gain factor was then calculated as:

$$K = y(\infty) - y_{st}(t_0) = 4.1 - 2.75 = 1.35 \qquad (2)$$

The time constant was determined using the tangent method, therefore obtaining:

$$T = 435 - 375 = 60 \text{ msec} \cdot 4 = 240 \text{ msec} \qquad (3)$$

With these three parameters identified, the approximate dynamical model of the DC motor is represented by the following first order transfer function:
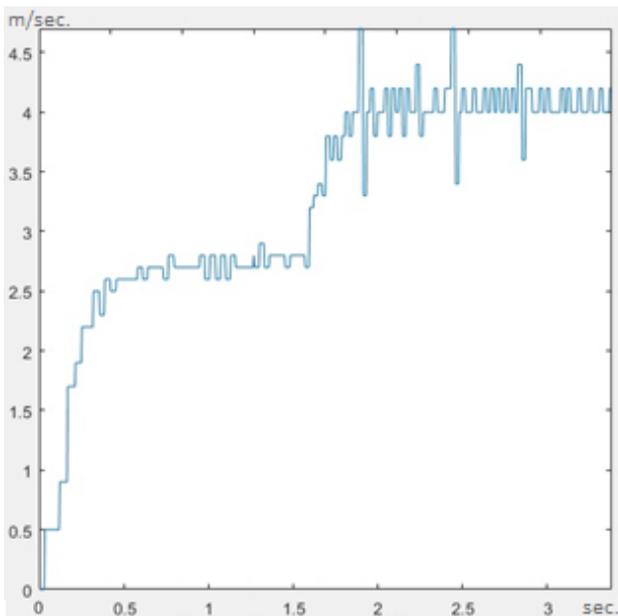
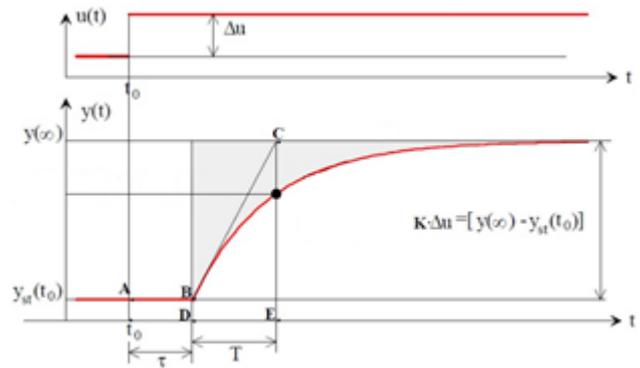$$H(s) = \frac{1.35}{0.24 \cdot s + 1} \qquad (4)$$

Fig. 10: Experimental determination of first order transfer function parameters

5.2. MATLAB/Simulink Simulation

A simulation was created with MATLAB/Simulink to compare the results of the approximated DC motor model to the real DC motor.

Fig. 11 contains the block diagram which simulates the Heaviside step applied to the DC motor model.

Fig. 12 shows the simulated response of the DC motor. This response is almost identical to the response of the real DC motor acquired from the microcontroller through Bluetooth wireless technology.
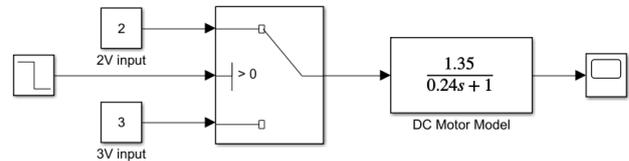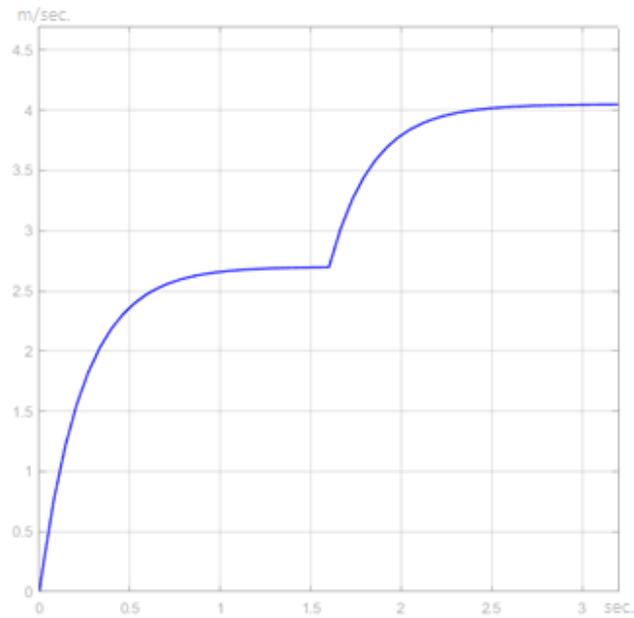

Fig. 11: DC motor simulation block diagram

Fig. 9: DC motor response to Heaviside step

Fig. 12: Simulated DC motor response to Heaviside step

6. CONCLUSIONS

Modelling different components of a technological process represents the first step for establishing an automated system. The approximated mathematical expression resulted from the modelling facilitates the possibility of creating a series of simulations to determine the optimal parameters for the model. The mathematical model is a simplified approximation of reality and it cannot accurately represent the complex system. The more accurate the description of the system behavior is, the more complex the mathematical model becomes.

The modelling can be done either through the analytical method, either through the empirical identification method. When the system is considered a black-box system, the identification method is usually used to obtain the model. To use this method, measurements of the input-output signals are needed. These measurements can be done with a microcontroller which can process the data locally or it can transfer the data to another computer for processing. The transfer is done either via wired or wireless communication.

This paper presents the modelling of a DC motor through the empirical identification method using Bluetooth wireless communication technology.

The microcontroller used actuated the DC motor through the H-Bridge interface and transmitted the data to MATLAB/Simulink through the Bluetooth module connected to the UART interface. The most important microcontroller's drivers which had to be implemented to model the DC motor were: UART driver for Bluetooth communication, PWM driver for actuating the DC motor, Encoder driver for calculating the rotation speed.

The MATLAB/Simulink GUI interface was designed to assure the connection to the microcontroller's Bluetooth module and to plot the received data. The data allowed to determine the transfer function of the DC motor using the experimental identification method based on the response to the Heaviside step used for first order transfer function parameters. The transfer function of the DC motor was simulated in MATLAB/Simulink obtaining an almost identical response as to the one from the real DC motor.

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