A Simulink-Blockset to Control Lego Mindstorms using Raspberry Pi

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Abstract. *The LEGO Mindstorms hardware is used at the RWTH Aachen University for educational purposes in undergraduate studies. It allows students to design and operate simple robotic systems. For the improvement of flexibility, the Raspberry Pi can be used as a faster alternative to the LEGO Mindstorms Brick, which in combination with the BrickPi allows us to control both actuators and sensors. In this paper, a MATLAB Simulink-Blockset is presented, which makes it possible to control LEGO Mindstorms using the Raspberry Pi. Interfacing LEGO Mindstorms with the Raspberry Pi based on Simulink might open up novel possibilities for advanced control engineering courses in graduate studies.*

Keywords

Raspberry Pi, MATLAB Simulink, LEGO Mindstorms, Control Engineering.

1. Introduction

Low-cost hardware like the Raspberry Pi or LEGO Mindstorms is used to introduce students to some real research problems. Using LEGO Mindstorms, simple mechatronic systems can be realized easily which describe important control engineering problems, for example the control of an inverted pendulum [1]. For the analysis of complex control systems however, it is desirable to have more flexibility in both software and hardware. A Simulink support package for interacting with the LEGO Mindstorms Brick [2] is available, which makes implementing control algorithms easier. However, one major limitation of using the Brick is that it can only interact with its proprietary hardware, which makes it harder to extend the system with other sensors or actuators.

The Raspberry Pi 3 Model B is therefore chosen as an alternative to the LEGO Mindstorms EV3 Brick, because of its higher clock rate, bigger memory size (see Tab. 1) and hardware extensibility. The usage of external hardware widens the variety of systems to analyze. Additionally, it is possible to interface the LEGO Mindstorms with the Raspberry Pi using a hardware extension called the BrickPi [3], which is produced and distributed by Dexter Industries. Similarly to the LEGO Brick, it features four sensor and four motor ports. Using the BrickPi and the Simulink support package for the Raspberry Pi [4] it is possible to create control algorithms which can run on the Raspberry Pi to control LEGO Mindstorms. In the following, a possible method for this is presented.

The paper is structured as follows: Section 2 presents the methods used for creating the Simulink-Blockset and the analysis of performance limits. In Section 3 the results are discussed and a conclusion is formulated in Section 4.

	Raspberry Pi 3 B	Lego Brick EV3
Clock rate	1.2 GHz	300 MHz
RAM	1 GB	64 MB

Tab. 1. Comparison of hardware properties. The Raspberry Pi is four times faster and has a much larger memory size.

2. Methods

The communication between the Raspberry Pi and the BrickPi is done via the Serial Peripheral Interface (SPI). The Raspberry Pi acts as the master and sends commands to the BrickPi, which responds as the slave by sending data back. A Simulink-Blockset is created, which automates all communication processes. Thus, in order to interact with the LEGO hardware, it is only necessary to drag blocks from the blockset and drop them into the main Simulink program (see Fig. 1).

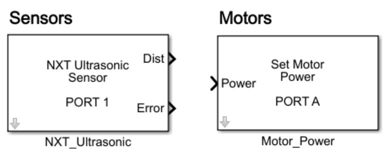

Fig. 1. Example blocks. Left: Block for reading out ultrasonic sensor values. Right: Block for setting motor power.

2.1. Realization of the Blockset

The support package [4] includes the ”SPI Master Transfer” block (see Fig. 2) which enables sending and receiving data bytes. Using this block and the commands which are needed to interact with each individual LEGO hardware, a block for each sensor and actuator is created. The commands are extracted from the C library of the BrickPi which is provided by Dexter Industries. Almost every block consists of an initialization subsystem, which is executed only once at the beginning of the program, and a continuously executed subsystem which retrieves the data (see Fig. 3). Similarly to the blockset which is implemented in the support package [2], masks are added to each block to provide a convenient way for setting parameters.

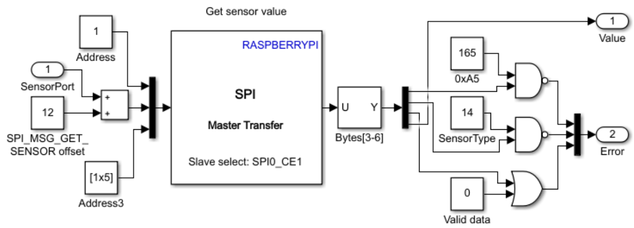

Fig. 2. Example of a communication subsystem. Byte transmission and reception via ”SPI Master Transfer” block.

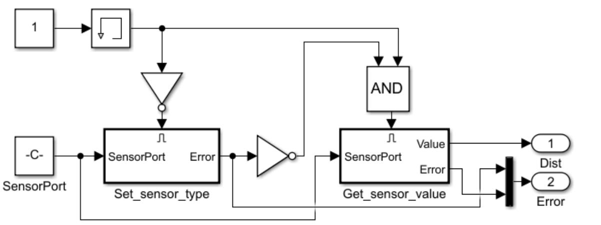

Fig. 3. Internal of a sensor block. Left subsystem is executed once at the beginning for initialization. Right subsystem is continuously executed.

2.2. Analysis of performance limits

For applications in control engineering, it is important to achieve real-time capability, which is why a measurement of maximum possible execution frequency of the blockset is performed. However, because direct measurement of the minimal realizable execution time in Simulink is assumed to be difficult, an approximation is used. The time step size of the Simulink program is decreased until a task overrun is detected at the Raspberry Pi. This is done with every LEGO motor and sensor separately and also with full load, i.e. with four sensors and motors attached.

3. Results and Discussion

The performance analysis shows that the block with the longest execution time needs to be executed with a program step size of at least 1.25 ms in order to avoid task overruns. In case of full load, at least 4 ms are needed (see Tab. 2). Thus, in theory, most control programs can be executed with a frequency of about 250 Hz. However, since the Raspberry Pi is not a real-time system, it does not guarantee this and the given limits should not be seen as tight bounds. As proof-of-concept, the created blocks are used to control a Segway-like robot making it stand in an upright position. The control program runs at 250 Hz.

	Minimal time step
Block	**1.25 ms**
Full load	**4 ms**

Tab. 2. Approximated lower bounds of time step. At full load, a maximum frequency of 250 Hz results.

4. Conclusion

The created Simulink-Blockset enables interaction with LEGO Mindstorms via the Raspberry Pi. Some blocks for certain sensors are not available yet, but the blockset is enough to provide a more flexible tool for advanced control engineering classes in graduate studies.

Acknowledgements

The seminar project described in this paper was supervised by Prof. Dr.-Ing. Dr. med. Dr. h.c. Steffen Leonhardt, Medical Information Technology, RWTH Aachen University.

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