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Design of a Single Line Half Duplex Protocol for Mechanical Rotary Table Systems

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In this study, a new communication protocol, which addresses the rotary table, has been designed. Developed system works over a single line and is using slip rings. The designed communication protocol ensures the half duplex communication for multiple stations over a single cable. During the protocol design, media access methods, coding techniques and multi-node synchronization techniques were examined. These techniques have been adapted, updated and combined for the study, during the formation of the communication protocol. The designed protocol was tested and verified in the simulation environment with original software, on the microcontrollers. The protocol is aimed to be open source, flexible, easily applicable and a new solution for the distributed control problems in the field of automation and for the rotary table systems in particular.

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1. Introduction

Today, many electronic communication systems have been designed and implemented because of the diversification of the production facilities and the increasing need for the unmanned automatic machines. The reliable serial communication is preferred in automated solutions and industrial communication sites. During the communication in industrial implementations, cable complexity constitutes greater problem than the other automational challenges, particularly in the rotary table systems. Therefore, researchers look for new serial communication solutions for rotary table mechatronic systems.

Martin Bates shared the most up-to-date information about the serial communication in his latest book, entitled "Interfacing PIC Microcontrollers" [1]. Chennakesavulu and Raghavi suggested a design and coding technique named ETI (Embedded Transition Inversion), which would minimize the phase difference between the clock pulse and the transmitted data within the serial communication [2]. Thompson examined in his study how tens of industrial communication protocols, which were developed by many different firms, were named and standardized [3]. Diaz-Olavarrieta and Baez-Lopez compared the other protocols which had properties similar to those of the LIN-Bus network system in their study, where they specified the requirements in the automotive electronics [4]. Murari and Lotto preferred communication with single line while examining the achievement of the high-vacuum conditions in the vacuum chambers, equipped with various heat sensors [5]. Fei-Huang Chang et al. examined the problems of a group of devices, while using the all-to-all broadcast method during the communication in the half duplex all-port model [6]. Song et al. reviewed the distributed setting valued approach problem in multiple noise sensor networks with the restricted communication data rate and presented two explanatory examples [7].

Integrated industrial systems incorporate subsystems, such as measurement, communication and control systems. Communication in such integrated systems is very important. The communication between the torque meter and the control system has been successfully accomplished with the half-duplex communication protocol in the study by Karayel and Yegin [8]. Zhong et al. introduced a novel two-step interference alignment beamforming algorithm for a multiple-antenna interference channel with uncoordinated interference. Algorithm presented by authors uses the minimum mean square error as a criterion to maximize the sum rate of the system [9]. Saunders, on the other hand, has approached the effects of communication in an artificial creative systems in his review article [10].

In this study, the developed protocol addresses serial communication, which is a fast and reliable communication method, to prevent the cable complexity. Time-code compatible synchronization and coding technique were implemented with various tests in order to provide half duplex transmission of the data over single line. The result was achieved using the media access method of time division multiple access (TDMA).

2. Rotary table system

The designed protocol has been implemented and tested on automotive hinge assembly-quality control production table, which includes a rotary table and five work stations. Base and moving arm of hinge are assembled by a rivet, formed using high pressure. Torque of produced hinge is defined by rivet tightness. In recent years, automobile companies require specific torque limits in order

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to improve production quality, comfort and ergonomy. Electronic control system and its protocol algorithm use distributed sensor values, so that hinge can ensure a quality usage. Control system is divided into two electronic boards: slave, on rotary table and master, on the machine body.

An alternative solution is presented in this study, in which all procedures for the assembly of the hinges and quality control are performed on the rotary table. Rotary table assembly system consists of five work stations, as seen in Fig. 1. These are loading and unloading, assembly, rivet scrubbing, torque control and labeling stations.

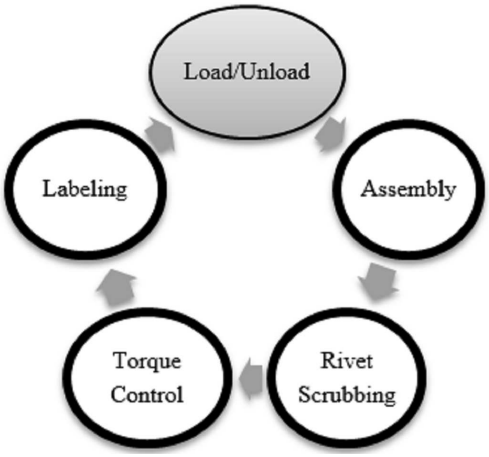

Fig. 1. Rotary table assembly system work stations.

The mentioned assembly system consists of subsystems that require synchronous working with each other. An extensive control system is needed so that the system can perform its functions in an efficient way. The control system collects data via digital and analog sensors controlled by slave module, which is located on the machine body. In other words, the distributed sensor-based control system has been found appropriate for the system.

3. Communication protocol

One of the problems, that occurred together with the popularization of the rotary table systems in industries, is the cable complexity. Numerous cables should be connected between actuators, sensors on the main table and similar elements on the rotary table to ensure communication. Rotary table is turning 360 degrees continuously, therefore the only solution to deal with these connections is using slip rings. When the capacity of the slip ring increases the cost increases significantly. Therefore reducing cable number is strictly important.

Data packages that will be sent over the data line are synchronized through the clock pulse in most of the communication protocols, which are sold commercially and each bit that forms the data is sent through this signal. However, the cable excess, which emerges as a result of gathering clock pulse, ground line and more than one data lines, can disrupt the communication in rotary table systems. Therefore, the designed communication protocol, that was developed to be used in industrial implementations, takes the half duplex activity as a reference and provides the data transmission with single line. The half duplex communication which is performed using a single line between the master and slave stations is schematized in Fig. 2.

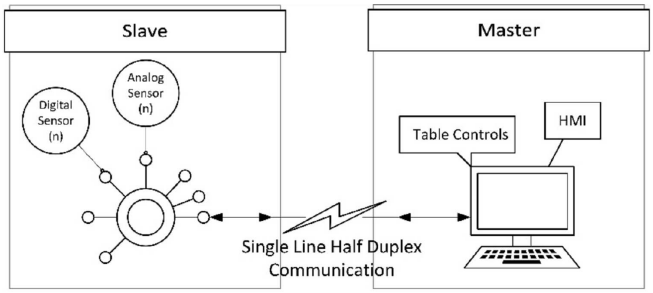

Fig. 2. Master-slave stations.

3.1. Relationship between the stations

This study is based on the development of a system that has many assembly and test station. These stations have to work with each other in integration, sensitivity and synchronization. Basically, this is achieved by the verification of the communication protocol by determining the necessary equipment after the preparation of a unique system structure and an appropriate algorithm and its integration into the main system. The task of the master station, which is positioned on the main body, independently from the rotary table, is to control the information that will come from the slave station with the reference values and to transmit the control result to the slave station on the rotary table. Various measurements are received from the sensors on the fixtures for the accept-reject approvals of the hinges positioned on the fixtures. This relationship is schematized in Fig 2. The system that was realized is shown in Fig. 3.

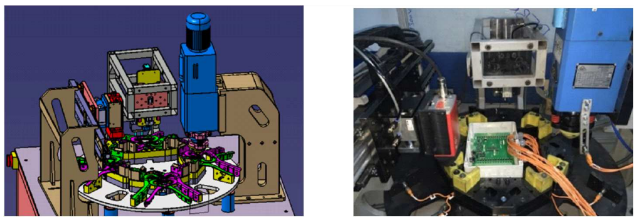

Fig. 3. Rotary table CAD data and completed system.

The control algorithm of the developed communication protocol relies upon the master-slave relationship, where the main table is considered as master and each station as slave. Main controller which takes the place of master is in continuous communication with the sensors at each station. It controls the whole system and reports the error when it notices a delay, error etc., at any station.

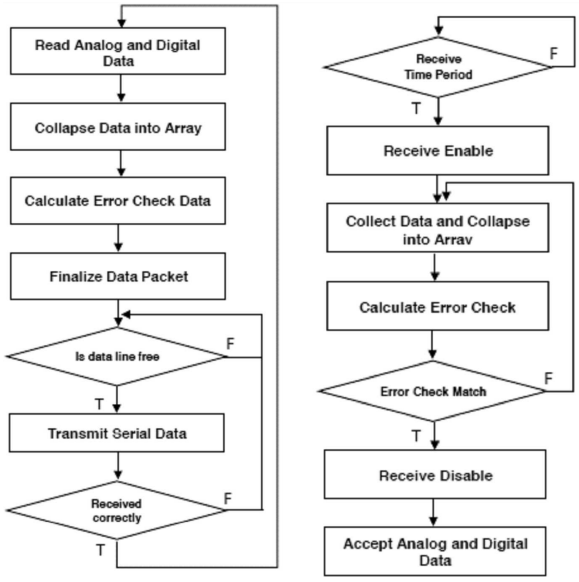

Fig. 4. Data transmit and receive flowchart.

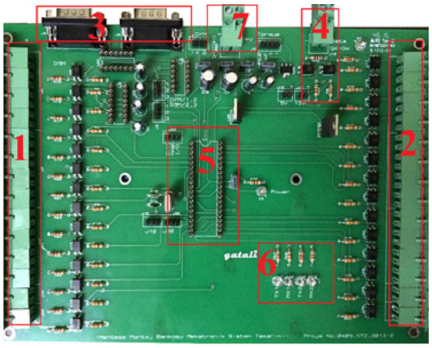

Fig. 5. Master and slave PCB. 1–input ports, 2–output ports, 3–serial communication ports RS 485 and RS 232, 4–single line half duplex communication, 5–MCU, 6–status LEDs, 7–power input.

This code flow is independent from the main loop with the sub-procedures. General algorithm of the designed protocol is given in Fig. 4 as a flowchart.

The electronic circuit designed for the automotive hinge assembly system is given in Fig. 5. This circuit can be used as master or slave module by changing the software. This is another advantage of the study, which makes it more practical and inexpensive.

3.2. Data package

Format of each data package sent using this protocol is shown in Fig. 6. The first bit that forms the data package is the start bit. The logical 0 (low) signal is always available when there is no data transfer over the line. Because the verified protocol would be used in industrial areas, it was considered to keep the line at the low level continuously, that is, at logical 0.

The line was at logical 0 as the start bit (the logical 1 (high)) was used and it would cause changes on the line. Two ID characters (ID1, ID2) are transmitted for the purpose of transmitting the data safely over the line after the start bit. The purpose of these characters is to begin the communication with the desired start data and therefore to enable the devices to recognize each other and to ensure their synchronization.

AEC and DEC bytes are check bytes, used to ensure that the analog and digital data are transmitted without any corruption or data loss by using CRC (cyclic redundancy check) methodology. After those start characters, the analog and digital data are transmitted (AD, DD). The counter device continuously queries this start bit and start characters, and after the confirmation, it transfers the 16 bit data (8 bit analog and 8 bit digital) into its memory and/or displays them. After the transmission of the 16 bit data, the signal on the line is again brought to the logical 0 in order to initiate another transmission.

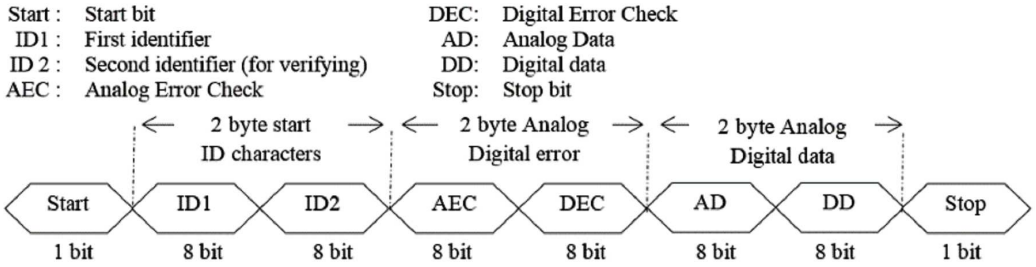

Fig. 6. Transmitted data package format and lengths.

4. Conclusions

The communication protocol developed within the scope of this study performs a half duplex serial communication, based on the master-slave relationship between the fixtures on the table in rotary table systems and the master station positioned on the main body. In this study, a protocol was designed and put into operation, which reduces the lines allocated for the clock pulse and the data down to a single line. This communication protocol needs only the data line between two nodes. The data are transmitted in half duplex mode. Length of the data packages was defined to be 50 bits during the process of the development of communication protocol and the transmission period of each bit within these packages was set to approximately 0.416 ms. The achieved communication rate was 2.4 kHz, depending on the baud amount.

It was tested that efficient communication was provided within maximum 60 meters distance, at the preferred communication rate. Because far distances are not an issue for the rotary table system, the baud rate of the communication was appointed as 2400 bps. Designed protocol's media access method is TDMA, maximum node count is 254 and the used topology is bus topology. Mainly designed for rotary table mechatronic systems, this protocol can be applied in development in other industrial areas. It is expected from the developed protocol to make great contribution to the industrial systems and the studies of the researchers and to fill the deficiencies.

Acknowledgments

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