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Automated Warehouse: Student Project within Courses Mechanisms and Microcomputers at The Technical College in Bjelovar

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***Abstract*— This paper describes the student project "Automated Warehouse". The project was done for the purpose of evaluation of learning outcomes in courses Mechanisms and Microcomputers. The aforementioned courses are integral parts of the curriculum of the Professional Programme of Study in Mechatronics at the Technical College in Bjelovar. Automated warehouse is a mechatronic system for controlling pallets with goods without human intervention. The paper presents the virtual design of the system, its mechanical construction and system control by means of a microcomputer.**

***Keywords*— automated warehouse, mechatronics, mechanisms, microcomputers**

I. INTRODUCTION

Mechatronics is a multidisciplinary field that integrates mechanical, electrical, computer and control systems into a whole [1]. Some areas of mechatronics are complex and change rapidly [2]. One of the first professional study programs in Mechatronics in Croatia has been the Undergraduate Professional Study Program in Mechatronics at the Technical College in Bjelovar [3]. The duration of this professional study program amounts to three years (six semesters, 180 ECTS). The curriculum of the Professional Study Program in Mechatronics educates students in the areas necessary for them to be able to understand the whole concept of mechatronics.

In the fourth semester students if the Professional Study Program in Mechatronics take courses Mechanisms and Microcomputers. The course Mechanisms familiarizes students with basic types of mechanisms, kinematic analysis of mechanisms, basic laws in mechanism dynamics and the synthesis of mechanisms [4]. The course Microcomputers deals with the architecture of microcomputers, connecting sensors and actuators to a microcomputer, programming microcomputers and connecting microcomputers to smart phones or computers [5]. For the purpose of evaluating learning outcomes in courses Mechanisms and Microcomputers, students are assigned to teams and make a mechatronic system that integrates a mechanical, electrical, computer and control system into a whole.

This paper presents a description of the student project "Automated Warehouse" as an example of a mechatronic system made by students for the purpose of evaluating learning outcomes in courses Mechanisms and Microcomputers. The development of technology and the cost of human resources encourage people to design automated units for manufacturing, services, transport and logistics [6]. The objective of the automated warehouse project is to minimize the costs of human resources and present the automation possibilities in a quality and efficient manner. The warehouse is operated by an operator via a smart phone by sending the order for a desired pallet from the warehouse. Upon receiving the information, the system independently goes to collect the desired pallet and brings it to the required place, without additional human intervention. Advantages of warehouse automation are reduced costs of workforce, faster transportation, the possibility of delivering larger amounts of goods within a unit of time and a lower impact of the human factor. A disadvantage of such systems may be observed through high costs of the system. Thus, it is important to pay attention to the cost-effectiveness, i.e. the needs for such automated warehouses.

The paper is organized as follows. Section II describes the project "Automated Warehouse". Virtual design and mechanical construction are described in Section III. Section IV presents the description of controlling the automated warehouse. Finally, Section V offers a short conclusion.

II. DESCRIPTION OF THE AUTOMATED WAREHOUSE

Figure 1 shows the automated warehouse. It consists of a Cartesian palletizing manipulator and a left and a right shelf for pallets. The palletizing manipulator is driven by four stepper motors. Three stepper motors are used for achieving a desired position in space, while the fourth stepper motor allows for tool rotation. The manipulator tool is a pallet fork used for collecting pallets and taking them to a defined

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position in the warehouse. The position in the warehouse is defined via a smart phone that sends the information about the desired position to an ATmega128 microcontroller via Bluetooth. The microcontroller controls the stepper motors for the purpose of achieving the desired position of the manipulator in the warehouse.

A pallet may be stored in the warehouse in any free position within the warehouse. The system records the warehouse status and prevents a pallet being positioned to a place that is already taken. A stored pallet may be removed from the warehouse via a smart phone. A total of 24 pallets may be stored in the warehouse. The operation of the automated warehouse may be seen on Youtube [7].

Fig. 1. Automated warehouse

III. VIRTUAL DESIGN AND MECHANICAL CONSTRUCTION OF THE AUTOMATED WAREHOUSE

A. Virtual model of the automated warehouse

The virtual model of the automated warehouse was made in the CAD tool SolidWorks®, and is shown in Figure 2.

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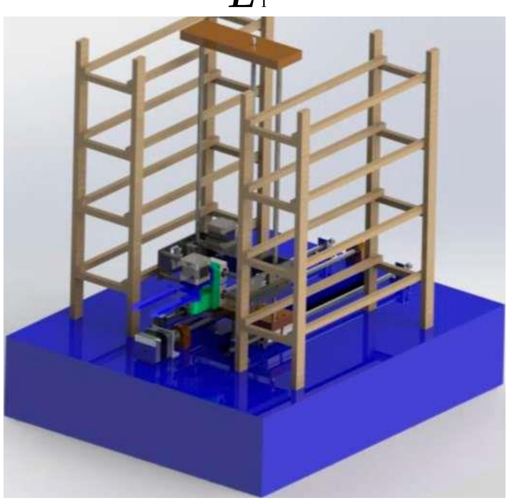

Fig. 2. Virtual model of the automated warehouse

The virtual model was used for simulating the movements of the Cartesian manipulator. By designing a virtual prototype, errors in mechanical construction are reduced to a minimum. Figure 3 shows the virtual model of the Cartesian manipulator with stepper motors, spindles and guides for moving along the x, y and z axes. The manipulator tool (pallet fork) is located on a carrier that moves along the z axis. The virtual model of the automated warehouse was used for creating a working drawing that was used for the mechanical construction of the warehouse.

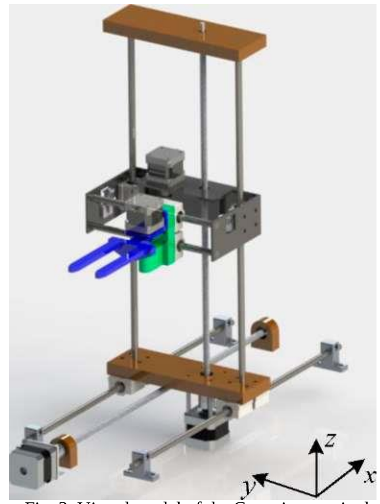

Fig. 3. Virtual model of the Cartesian manipulator

B. Mechanical construction of the automated warehouse

Mechanical construction of the automated warehouse included the following components: stepper motors (Nema 14, Nema 17), spindles, bearings, couplings and aluminum guides. The stepper motors Nema 17 were used for translation movements along the x and y axes due to greater load on these axes. For movements along the z axis and the rotation of the manipulator tool, stepper motors Nema 14 were used. Spindles are trapezoidal with an 8 mm step. The bearing bore diameter amounts to 5 mm, while the bearing outside diameter amounts to 16 mm.

The dimensions of the automated warehouse stand are 600x500x132 mm, and it was made of veneer. Inside the stand there is a control system of the automated warehouse. on the stand there are two shelves for pallets (see Fig. 4) that consist of three columns and four rows. A total of 24 pallets may be stored in the warehouse (12 pallets on the left, and 12 pallets on the right shelf). The shelves were made of wooden rods.

Fig. 4. Shelf for pallets

Carriers for threaded rods and aluminum guides were made of Bakelite. The dimensions of the carriers are 190x60x15 mm. Carriers were made using a CNC machine according to the working drawing of the carrier (see Fig. 5).

Fig. 5. Construction of Bakelite carriers using a CNC machine

The pallet fork carrier (see Fig. 6) was made of sheet metal. The thickness of sheet metal amounts to 3 mm, and it was bent by machining.

Fig. 6. Pallet fork carrier

Pallet forks and pallets (see Fig. 7) were printed using the 3D printer MakerBot Replicator 2X. The CAD model of pallet forks and pallets was saved in the STL format compatible with the 3D printer.

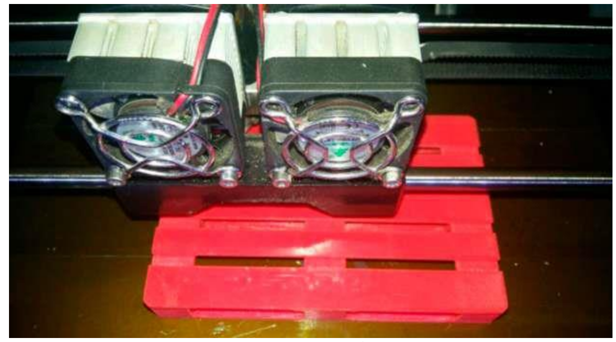

Fig. 7. 3D printing of pallets

IV. AUTOMATED WAREHOUSE CONTROL

Electronic schematic of the automated warehouse control system is shown in Fig. 8. The automated warehouse is controlled by an Atmel ATmega128 microcontroller [8]. The development environment with an ATmega128 microcontroller is shown in Fig. 9. The ATmega128 microcontroller was programmed in the programming language C using the programming environment Atmel Studio [9].

Four drivers for stepper motors BL-TB6560 are connected to the ATmega128 microcontroller (see Fig. 10). The BL- TB6560 driver is used for precise control and changing the rotation direction of a stepper motor. For the purpose of preventing overload and overheating, the driver has overcurrent protection. Stepper motors Nema 14 and Mena 17 are connected to the drivers. The stepper motors allow for the motion of the Cartesian manipulator and the rotation of pallet forks. The ATmega128 microcontroller sends a series of impulses to the BL-TB6560 driver that subsequently turns the stepper motor. In order for a stepper motor to rotate for one turn, the BL-TB6560 driver must be sent a total of 1600 impulses. The spindle step amounts to 8 mm. Therefore, the Cartesian manipulator moves by 8 mm for one turn of the stepper motor. If it is necessary to make a movement amounting to 40 mm along the x axis, Atmega128 microcontroller must send a total of 8000 impulses to the stepper motor driver for the x axis.

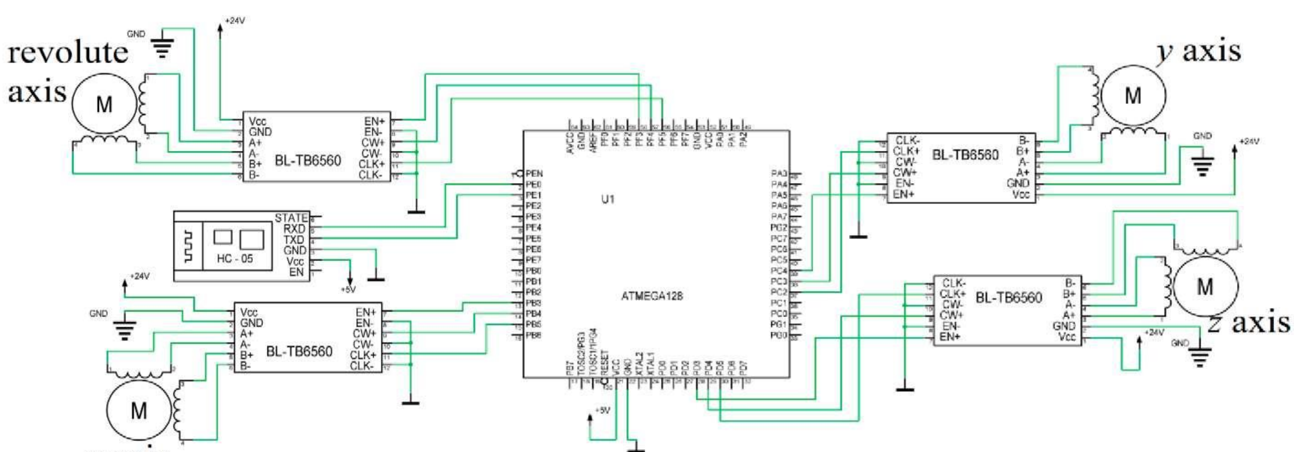

Fig. 8. Electrical schematic of the automated warehouse

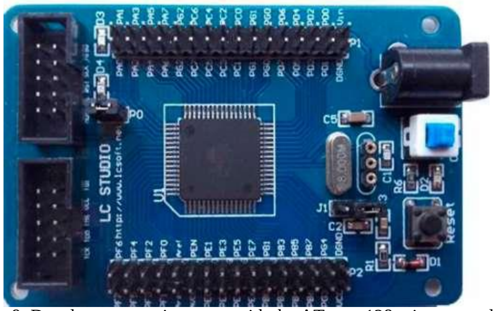

Fig. 9. Development environment with the ATmega128 microcontroller

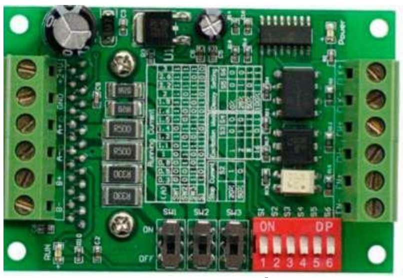

Fig. 10. BL-TB6560 driver

Figure 11 shows a pallet shelf with the column and row indices in the *x-z* coordinate system. The shelf consists of three columns and four rows.

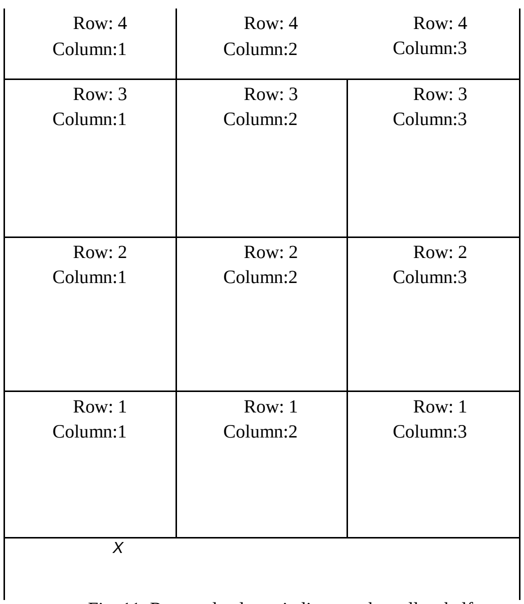

Fig. 11. Row and column indices on the pallet shelf

Table 1 shows the number of impulses that have to be sent to the stepper motor driver for the x axis in order for the Cartesian manipulator to move to the position of the index of the *i* column along the x axis. If the column with index 2 is selected, the microcontroller will send 49200 impulses to the stepper motor driver, and the Cartesian manipulator will move by 246 mm along the x axis. Table 2 shows the number of impulses that must be sent to the stepper motor driver for the *z* axis for the purpose of moving the Cartesian manipulator to the position of the index of row *j* along the *z* axis. If the row with index 4 was selected, the microcontroller will send 119600 impulses to the stepper motor driver, and the Cartesian manipulator will move by 598

TABLE I. PARAMETERS OF MOVING THE CARTESIAN MANIPULATOR ALONG THE X-AXIS

Column index, *i*	Number of impulses	Shift [mm]
1	9200	46
2	49200	246
3	89200	446

TABLE II. PARAMETERS OF MOVING THE CARTESIAN MANIPULATOR ALONG THE Z-AXIS

Row index, *j*	Number of impulses	Shift [mm]
1	0	0
2	19800	99
3	39800	199
4	59800	299

mm along the z axis.

Along the y axis the Cartesian manipulator is moved by 70 mm (14000 impulses) to the left or to the right side, depending on the shelf selection. The rotation of pallet forks by 90° is achieved by sending 400 impulses to the stepper motor driver for the rotation of pallet forks.

The connection between a smart phone and the ATmega128 microcontroller has been achieved via Bluetooth module HC-05. The ATmega128 and the Bluetooth module HC-05 communicate by UART communication. Depending on the contents of the message sent from the smart phone, the microcontroller determines the final position of pallet forks. The message sent to the microcontroller from the smart phone has the following contents: "Rxij" or "Lxij". The first sign in the message may be 'R' or 'L'. By selecting this sign one selects the left or the right shelf. The second sign (x) in the message may have the values '0' and '1'. If x = '0', the pallet is placed in the warehouse, and if x = '1' , the pallet is removed from the warehouse. The third sign (i) in the message defines the column index on the shelf. The fourth sign (j) in the message defines the row index on the shelf. If the message sent via the smart phone contains "R123", the pallet placed on the right shelf in the second column and third row will be removed from the warehouse.

V. CONCLUSION

Mechatronics is a complex field that involves the area of mechanical engineering, electrical engineering, computer science and control systems. It is difficult to explain the notion of mechatronics to students in the scope of a single course. The student project "Automated Warehouse" is an example of a project that was made within courses Mechanisms and Microcomputers, which in their contents encompass all areas of mechatronics. Student projects in courses Mechanisms and Microcomputers are practical projects. Students have taken great interest in such projects, so this approach to evaluating learning outcomes in professional study programs in Mechatronics may serve as an example of good practice.

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