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MECHANICAL DESIGN OF A CARTESIAN ROBOT

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Abstract: This paper investigates the assembling options of a cartesian type robot, which can be used for material handling or 3D printing purposes. The structure has three ball screw driven linear units, which will be controlled by a microcontroller. The requirements of the structure to use as a 3D printer are defined. The solution selection matrix is constructed in order to choose the appropriate configuration of the system.

Keywords: *Cartesian robot, 3D printer, Solution selection matrix*

1. INTRODUCTION

Nowadays 3D printing is a widely used technique to achieve cost effective prototypes. A cartesian type robot containing three prismatic joints to construct the kinematic chain of the system can be suitable for this purpose. Cartesian robots can be used not only as 3D printers, but also in industry for various workpiece moving and positioning tasks. Its kinematic description is the simplest among the different common kinematic arrangements (Spong, Hutchinson, & Vidyasagar, 2006).

There are papers which deal with the design and use of cartesian robots. Paper (Civelek & Fuhrmann, 2023) presents the control of a Cartesian robot with mixed reality interface containing virtual buttons and virtual gloves. A gantry type Cartesian robot was developed for automation purposes at the University of Udine in the beginning of the 2000's (Gasparetto & Rosati, 2002). Cartesian 3D printers are common in additive manufacturing with Fused Filament Fabrication (FFF) technique. A 3D printer with crossed gantry design is investigated in (Wolf, Werkle, & Möhring, 2024) to analyse the printing performance with stepper and servo motors. In this article, two motor types were compared according to several aspects, e.g., dimensional accuracy, printing speed, vibration etc., servo motors are clearly more advantageous.

The main aim of the paper is to develop a linear robot, which is capable to serve 3D printing and material handling options. Three linear actuators and servo motors with its controllers are used to build the robot. These elements shown in Figure 1 are provided by Power Belt Ltd.

Section 2 deals with feasible assembling options for robotic structure. Furthermore, the section contains the requirements of the unit and the evaluation method of the feasible solutions. The mechanical, electrical development of the robot and the programming task will be performed soon, some information related to the mechatronic design is described in Section 3.

***Figure 1.** The linear units (3. – 5.) and one of the motors, motor drivers (1., 2.)*

2. EXAMINATION OF ASSEMBLING OPTIONS

The 3 linear actuators of different sizes and load capacities can be assembled in various ways. This Section introduces briefly these solutions.

Since it is a mechatronic system, it is worth using one of the important parts of methodical machine design, the creation of structural variants, to build such a system (Jakab, 2013). This method is mainly used in the case of machine tools. In the course of the formation of the structures, it can be determined based on the elementary movements of the actuator chains, how many ways the mechatronic system can be built. A specific structure includes the division of movements and which of these subunits is built on what.

This includes the fact that the number of actuator units performing elementary movements determines the exact degree of complexity of the planned mechatronic system. This is characterized by the number of subunits performing elementary movements, with the letter D (Dimension) next to it (Szabó, 2024). Since three compact units perform elementary movements, it is a 3D machine. When creating the structure versions, it must be taken into account that the tool (s) or the workpiece (m) is moved by the given compact units (Szabó, 2024). The extruder can be considered a tool here.

Based on these, the number of first-degree assembling options can be calculated as follows:

$$m_1 = 2^D = 8. \tag{1}$$

If all movements are built on each other, there is no division of movements for the given structure. If there is a movement that is not based on another movement, then it is a movement division.

Furthermore, it is an important aspect where the unit operating in a specific direction is in the construction line. This is given by the order of the given movement, i.e., the orderliness (Szabó, 2024). The orderliness specifies how many subunits move either the tool or the workpiece.

Table 1

Possible structures

No.	**Without movement division**	**No.**	**With movement division**
1.	X(s,1), Y(s,2), Z(s,3)	13.	X(m,1), Y(s,1), Z(s,2)
2.	X(s,1), Y(s,3), Z(s,2)	14.	X(m,1), Y(s,2), Z(s,1)
3.	X(s,2), Y(s,1), Z(s,3)	15.	X(s,1), Y(m,1), Z(s,2)
4.	X(s,3), Y(s,1), Z(s,2)	16.	X(s,2), Y(m,1), Z(s,1)
5.	X(s,3), Y(s,2), Z(s,1)	17.	X(s,1), Y(s,2), Z(m,1)
6.	X(s,2), Y(s,3), Z(s,1)	18.	X(s,2), Y(s,1), Z(m,1)
7.	X(m,1), Y(m,2), Z(m,3)	19.	X(s,1), Y(m,1), Z(m,2)
8.	X(m,1), Y(m,3), Z(m,2)	20.	X(s,1), Y(m,2), Z(m,1)
9.	X(m,2), Y(m,1), Z(m,3)	21.	X(m,1), Y(s,1), Z(m,2)
10.	X(m,3), Y(m,1), Z(m,2)	22.	X(m,2), Y(s,1), Z(m,1)
11.	X(m,3), Y(m,2), Z(m,1)	23.	X(m,1), Y(m,2), Z(s,1)
12.	X(m,2), Y(m,3), Z(m,1)	24.	X(m,2), Y(m,1), Z(s,1)

Since movement division and orderliness are also considered, it can be stated that second-degree structures are created. The number of structures is given by the following formula:

$$m_2 = (3D + 1)! = 24. \tag{2}$$

This means that 24 different structures can be formed with 3 subunits. The codes of the structures are illustrated in Table 1. The structure code contains the direction of the elementary movements (X, Y or Z), element to be moved (s: tool or m: workpiece), and orderliness. Three assembling options are shown in Figure 2 and Figure 3.

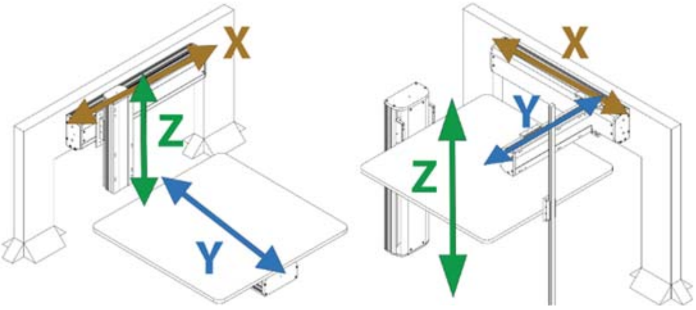

Figure 2. *Examples for parallel division of movements: X(s,1), Y(m,1), Z(s,2); X(s,1), Y(s,2), Z(m,1)*

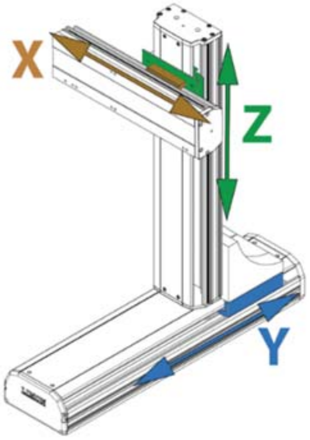

Figure 3. *An example for X(s,3), Y(s,1), Z(s,2) construction*

Requirements of the structure

Among the construction options, the most suitable one must be selected, which helps the robot to perform its task. For this, it is worth comparing the solutions with each other, taking into account different aspects, for which it is advisable to use the comparison of the feasible solution variants.

A total of 5 aspects were defined in relation to the system, these are:

- A: Load capacity,
- B: Installability,
- C: Size of the workspace,
- D: Nature of worksplace,
- E: Incurred costs.

The nature of workspace describes that in which workspace can more widely used workpieces be made. The most important aspects are the Load capacity and Installability. The size of the workspace is also important, but the differences between the concepts can be considered minimal.

Evaluation of solutions

The assembling options will be evaluated by using the so-called solution selection matrix. The interval of points that can be given for each solution with respect to each criterion is 1-20. According to subsection 2.1., there are five criteria. The most appropriate solution will be the one for which the sum of the points given for the criteria turns out to be the smallest. The result of the solution selection matrix can be seen in Table 2.

Table 2

The solution selection matrix

	A	**B**	**C**	**D**	**E**	**SUM**
3.	13	7	20	1	7	48
4.	14	1	9	7	1	32
6.	19	3	10	11	3	46
10.	16	4	19	6	2	47
13.	2	10	1	3	12	28
14.	4	11	8	9	14	46
15.	1	9	3	2	11	26
16.	3	12	4	4	13	36

In advance, the assembling options were analysed, and only viable structure variants are included in the table. Based on the matrix, the best solution is the fifteenth, which has the following code X(s,1), Y(m,1), Z(s,2), and it can be seen on the left side of Figure 2.

3. FUTURE PLANS

Based on the selected structure, the mechanical design of the workspace of the robot began. A frame was designed for the robot (see Figure 4), on which the compact units and the electronic devices that will be used and selected in the future can be attached.

For the proper functioning of the robot, it will be essential to carry out electronic design and electrical connections. Since the controllers belonging to the servomotors are able to receive STEP and DIR signals, a microcontroller-based panel will be necessary that will be able to produce these signals in the knowledge of the appropriate movement instruction. The block scheme of the desired system is shown in Figure 5. The control system must be able to interpret the G code generated after slicing the 3D model.

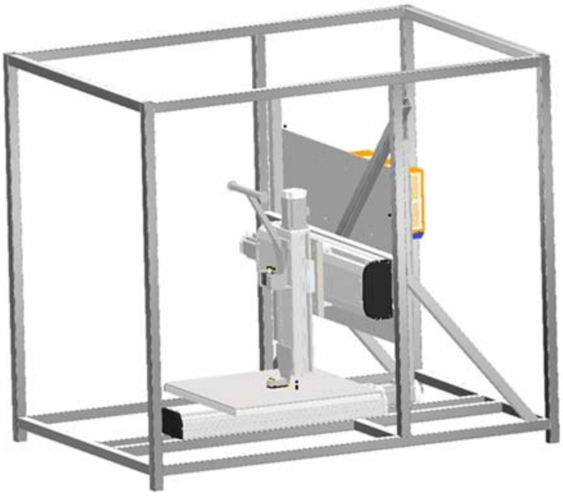

Figure 4. *Model of the system to be implemented and its frame*

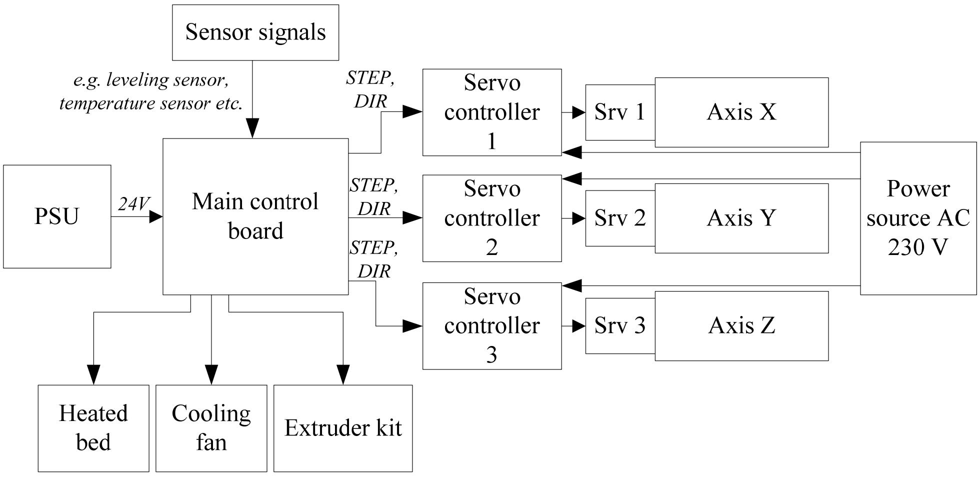

Figure 5. *The block scheme of the control*

4. SUMMARY

The article dealt with the exploration of the structural variants of a Cartesian robot suitable for 3D printing. Out of the 24 structural variants, the 8 viable constructions were compared according to 5 criteria using the solution selection matrix.
Mechanical design of the best version has already begun and will continue in the future. Furthermore, the control and connections belonging to the system are also expected in the near future. After the construction of the system, it will be necessary to complete tests, which will cover, e.g., for positioning accuracy and measuring the size of the workpiece.

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