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Industrial Robots in the Era of Digitalization: Validation of Structures

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Abstract
Large Scale Optimization is a very well-known concept in the context new manufacturing era. There are many applications focused on supply chain and intelligent or smart manufacturing. As part of flow optimization is substituting some workplaces with robotic structures (industrial robots, manipulators, cobots, etc.). Thus, one challenge is to get a good process design, with optimum systems use, with business impact, return of investment (from financial and human resource point of view). Another challenge is to choose the kinematic structure oriented on station's requirements. The robots are particular form of automation with significant costs that increase with the number of joints. But, in the context of Industry 4.0 revolution the use and design of robots and kinematic chain workstations it changes.

Keywords
manufacturing, optimization, robot, cost reduction, efficiency

1. Introduction. Industry 4.0

General concept about an industrial company is that consists of sales, operations and finance. More than that [1], these actions are defined by marketing, finance, design, manufacturing and sales. If these actions are more refined, the design includes concept, development, industrial design, technology, manufacturing of a product. With other words it is designed a product based on sell ability of it, corresponding to market requirements, company's technology, at the lowest possible cost, in the shortest possible time.

The term Industry 4.0 was first used in Germany around 2011 [2] and it is associated to fourth Industrial Revolution. This phase is also associated to Digitalization and Networking applied to manufacturing systems [3]. Despite of the increasing use of the term, the Industry 4.0, there are still lacks of definitions [4].

In ”Recommendations for Implementing the Strategic Initiative Industrie 4.0”, a report published by Acatech in 2013, three key features are highlighted: "horizontal integration through value networks, end-to-end digital integration of engineering, and vertical integration and networked manufacturing" [2, 5]. The horizontal implies to integrate all activities that add value to a product, end-to-end is associated to traceability of products, while vertical integration implies all the organization's levels. Thus Industry 4.0 is, in fact, an optimization intra-company flows and an inter-organizational integration through supply chains [6-9]. But, current manufacturing systems are, in fact, a mix between new technologies and traditional manufacturing processes. To upgrade a company to the new concept implies, besides technology aspect, human resources training, the essential element in the development of a company: costs, or economic efficiency.

The challenges of Industry 4.0 are economically, technologically and organizational, all these singular and interconnected. Technological challenges are generated by the need to integrate existing infrastructure and supply chains into a digital system. Thus, the concept of Industry 4.0 refers to intelligent networking of machines, processes based on the concept of Cyber Physical System [10] that evolutes to Cyber Physical Production Systems, Smart Factory [11]. To understand the implication and concept, there was developed a model: Reference Architecture Model Industry 4.0 (RAMI 4.0), by

German manufactures [10]. In Figure 1 is shown the model of RAMI 4.0 architecture. This model summarizes the principles of design from Industry 4.0 point of view: service-oriented reference architecture; intelligent cyber physical production systems (CPPS); interoperability between CPPS and humans; adaptability and flexibility; optimization for equipment effectiveness; data integration; reliable and secured communications; data security.

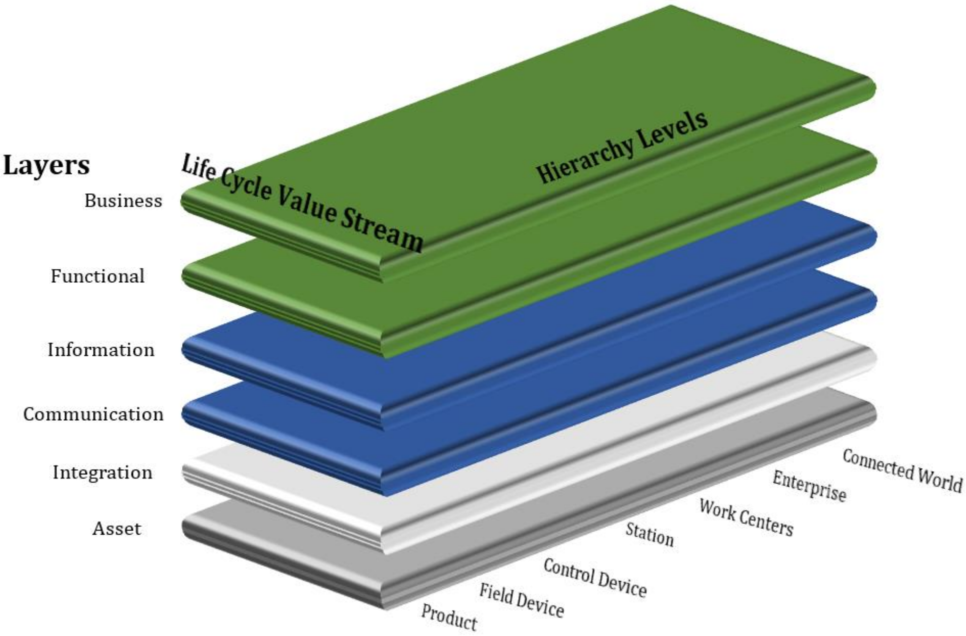


Fig. 1. RAMI 4.0 architecture [10]

As it can be seen, RAMI 4.0 [10] is a three-dimensional coordinate system that characterized the Industry 4.0 systems. The ”Hierarchy Levels” is an informational automation required by the different functionalities of company. The ”Layers” are the specifications imposed to a machine-tools or equipment. The last dimension, ”Life Cycle Value Stream” is given by the life cycle of facilities and products.

The existing manufacturing system should adapt to the new concept, as it is too expensive the implement new lines. It is hard to adapt an existing workstation to a new IT system, which connects machine to whole organization [12]. This happens because in tradition manufacturing, workstations are not all capable to transmit information both from machine and product point of view. This implies changing the workstation by adding a control system, full of sensors and controller. The question is if it is possible and the manufacturers will do that. The most probable answer will be ”no”. It is too expensive for manufacturers and to much work to do. Thus, choosing a dedicated system, with communication implemented is the correct solution both technically and financially point of view.

From robotic automation point of view, Industry 4.0 comes with a different approach, based on the idea of automatic flow of information, materials, goods and product. Thus, the new era of robots are programming using augmented reality, thus the classical programming interface or teach pendant are substituted by VR devices that allow users to program robot directly to the workstation. The control system is based on Artificial intelligence (deep learning or Natural Language Processing). Furthermore, the last years introduce the concept of corobot or collaborative robot which is a kinematic structure designed oriented on the desired movement at the workstation that has a direct interactivity to the human operator.

In the literature a very important step in implementing robotic process automation is the simulation one, used in the stage of developing and creation of new production lines. In this paper is presented an application, developed in Matlab, that allow the user to gain the appropriate structure of a robot. The application will be developed thus it will include the model of the system and simulates the behavior of different structures.

2. Robotic Process Automation: Solution for Increasing Efficiency

An industrial robot has been defined by ISO 8373 as " An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications" [13].

Cost reduction and increase efficiency are the general tasks of any company. To achieve this desiderate it should be considered a team work and to digitalize as much as possible to process of predesign of a product, flow, manufacturing.

Optimization is a closed-loop process, with continuous backtracking of efficiency indicators, with continuous applied quality instruments.

When talking about optimizing the production flow, it is considered designing the process and the manufacturing facility such that workflows are in straight lines or as closed as possible of that; distance from one workstation/ work center to the next are as short as possible; inventories and tools are located as closed as possible to where they are needed.

Is different case when it is required to increase efficiency to a specific work place. There are some directions that we are looking for but there are no standard solutions or choices. Thus, the directions are: quality of human resource (skills, qualification, time norm, etc.) and machine or equipment productivity, efficiency, manufacturing capacity.

Focusing on equipment the decision of implementing a robotic structure should be carefully taken because the main risk is to spend to much money on an structure much more complex that it is needed. There are a lot of reasons why a robotic process automation is the solution for optimization (Table 1).

Table 1. Reasons of using robotic process automation (based on [14])

Reasons	Detail
Accurate data entry	- numerical command and control; - environment gives numerical input through sensors;
No down-time	- medium efficiency is around 98% that means short time for maintenance (this percent includes time for reupdating software and program)
Reduce blockage and scraps	- on average, an employee makes 10 errors out of every 100 steps, a robot has a pose repeatability between ± 0.1 mm to ± 0.01 mm or even less
Increase productivity	- it is considered that, approximately 1 minute of work for a robot is equivalent of 15 minutes of work for a person (thus is reducing the cycle time);
Fast implementation	- faster than training new employee but it should be done by a qualified person
Easy to scale	- are easily to scale up or down also from cycle time point of view if the production is increasing or decreasing;
Minimal IT resources and digitalised system	- similar to NC machines; - facilitate implementation of a strategy of Intelligent automation
Data security	- high level of data security may be implemented
Costs	- between one-third to one-ninth annual loaded wages
Return on investment	- varies between 30 and as much as 200% in the first year
Standardizing processes	- same structures inside the whole company or for all companies in the field

When decided to choose between many solutions one of them being implementing a robotic process automations it should be considered the process disturbances, the speed of implementation and the predictability of the process (Figure 2).

3. Robotics Selection Based on Manufacturers and Statistics

The selection of a robot for a particular application is defined by performance required to satisfy the process needs and as well as manufacturers' solution developed for the specific application. There is no singular solution for one application because, rarely the input data are the same. For example, in the case of automated cutting, the robot may be implemented to carry the tool to the part or the part to the tool. The solution is different one, even if the process of cutting is the same, the result, from part and process point the view is the same.

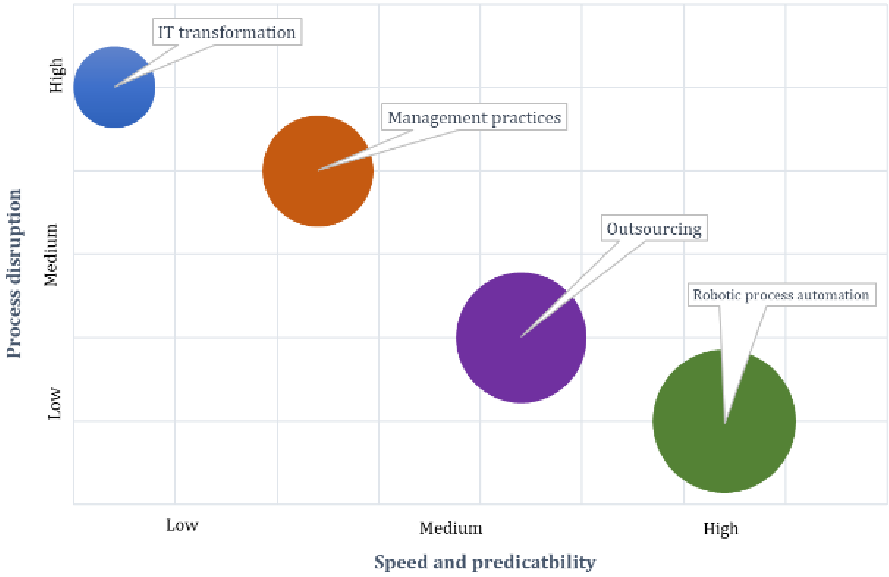


Fig. 2. Solution to optimize a manufacturing system

Therefore the process of robot selection is often iterative, requiring a number of different approaches to be considered before the optimum solution is defined [14, 15].

3.1. Criteria of selection based on manufacturer options

Researches approach the problem of selection of robotic structure in different ways. Thus, there are the manufacturer sites, or dedicated sites (as globalspec.com) that starts the selection by choosing the field (Table 2).

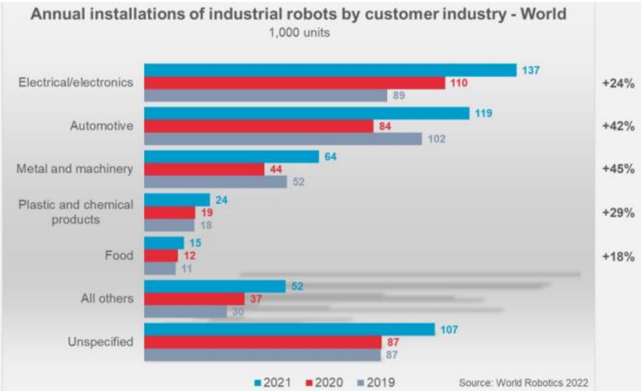
Table 2. Selection of robotic structure based on manufacturer's sites

Steps	Characteristics/ Examples	Advantages/ Disadvantages
Defining the purpose/ field	- additive manufacturing; painting; gluing; arc welding; assembly; drilling; material transport; pick-and-place, etc.	- selection of a specific structure by statistical data (the most often used kinematic for the selected purpose);
Payload	- micro robotics to heavy	- user may select the structure based on the maximum or minimum payload of the product; - if the search is done on manufacturers sites there may be selected only their specific values;
Reach	- different values	- user may select the structure based on the maximum or minimum reach; - if the search is done on manufacturers sites there may be selected only their specific values and, generally, there is no possibilities for choosing an interval

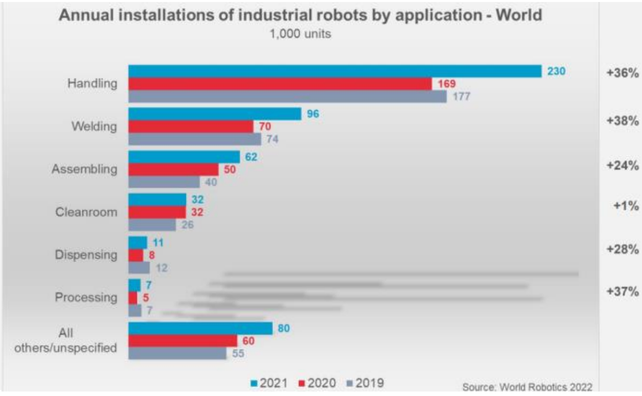
The main problem that appears is that these selections should be done by a qualified employee, that knows very well the working principle of the robots, knows kinematic enough to be able to correlate the workstation data and the robot structure. This an important disadvantage.

3.2. Worldwide robotics – selection of industry

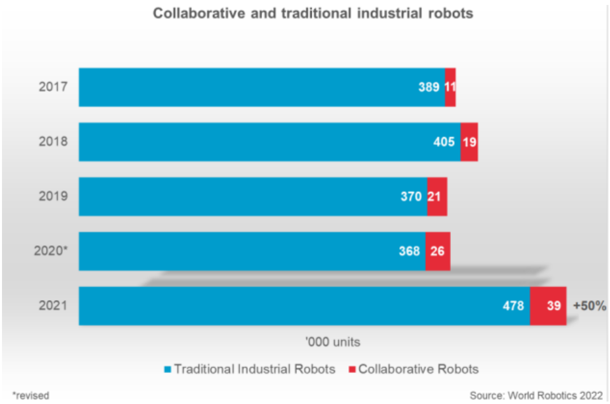
Because any existing selection application starts with selection of domain, it was analyze the evolution of these fields, according to International Federation of Robotics [16]. In the following are presented the statistical data, according to witch, *Electronics* is the major customer of industrial robots (Figure 3a), *Handling* is most important application – 44 % (Figure 3b), *Traditional industrial robots* are still dominated the market, but there is a significant growing of collaborative robots (Figure 3c). The dominant market is Asia (Figure 3d). China is the first market (51% of the market), followed by Japan (22 %) and United States (14 %). Summarizing data, in China and Japan the dominant market is *Electronics* while in United States the *Automotive* is the first industry (Figure 3d).



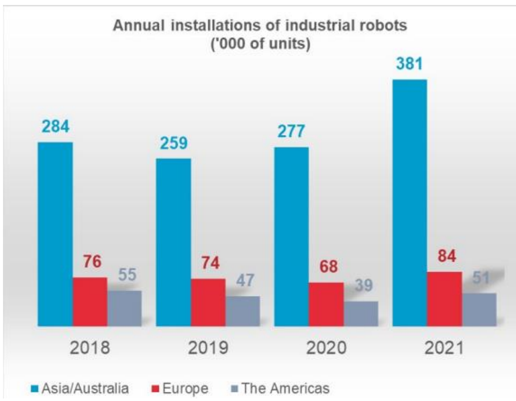
a) Industrial robots by customer industry



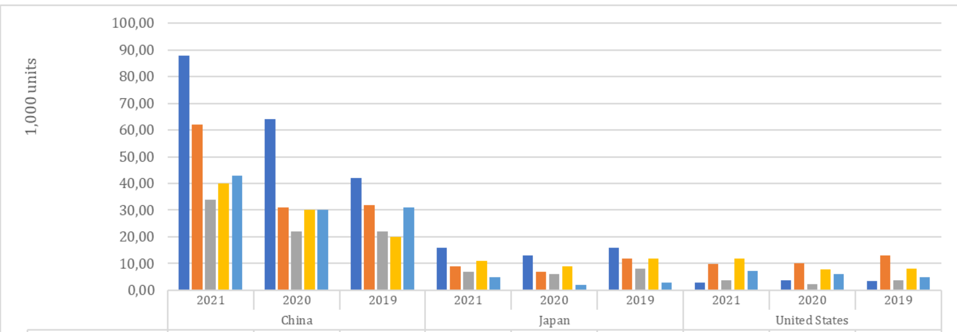
b) Industrial robots by application



c) Types of robots



d) Market evolution by continents



	China 2021	China 2020	China 2019	Japan 2021	Japan 2020	Japan 2019	United States 2021	United States 2020	United States 2019
Electrical/ electronics	88	64	42	16	13	16	2,8	3,7	3,4
Automotive	62	31	32	9	7	12	9,7	10	13
Metal and machinery	34	22	22	7	6	8	3,8	2,2	3,7
All others	40	30	20	11	9	12	12	7,9	8
Unspecified	43	30	31	5	2	3	7,1	6,2	4,9

Electrical/ electronics Automotive Metal and machinery All others Unspecified

d) Industries in the first three countries

Fig. 3. Evolution of industrial robot [16]

Based on the above data, the application will include, in a general way, four industries: electronics, automotive (manipulators or industrial robots), metal processing and all others.

4. Computer-Added-Validation of Robot Structure

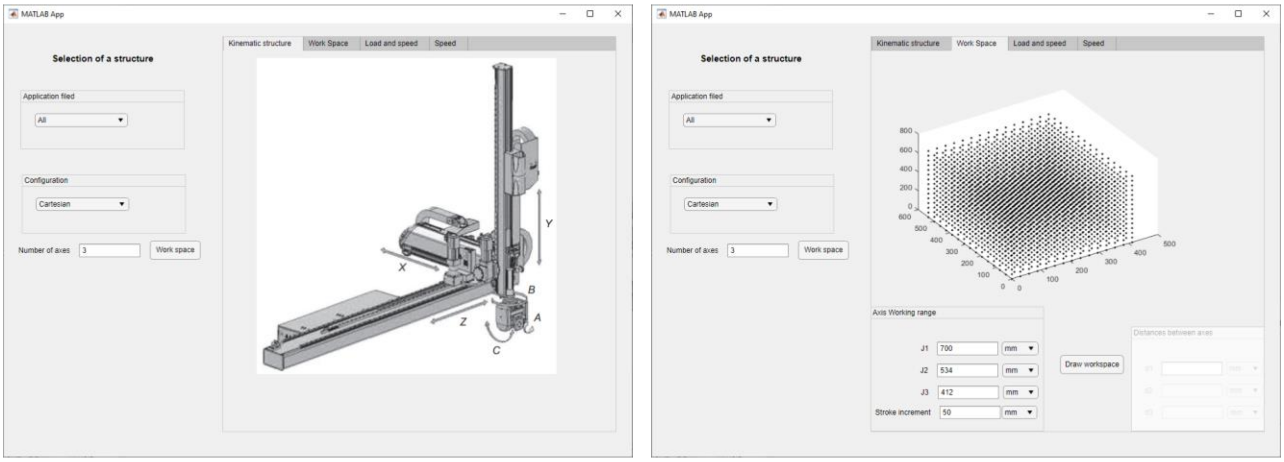
To help the designer of the workstation to find if a specific robotic structure is correct, appropriate for requirements, in the following there are presented the steps (Table 3) and application designed by authors, using Matlab.

The structure of the application has an educational interface thus being able to be use not only the field specialists.

Table 3. Steps of computer-added-selection of robot

Steps	Characteristics
Application	Based on the statistics (Figure 3) the user has as options: *Electronic/ Electrical*; *Automotive*, *Metal and Machinery*, *Other* or, the option *All* when not the application is the defining parameter
Structure	User may select between: *articulated*, *Cartesian*, *cylindrical*, *gantry*, *parallel* or *SCARA* structure. For each selected structure there is an imagine that helps the user. There are also two options, *Other* and *All*
Number of axes	Number of axis may be selected, or, it will result based on working ranges
Reach	Values given in [mm]. It help to define working space. There may be introduce a value, and based on reverse kinematic will determine the movements in each joint, or it may be introduce for each joint and then will be determined the work space. The value or values for this parameter is taken, by the user, from workstation layout (distance between buffers, machines, equipment, are of input/ output of parts, etc.)
Payload	Numerical value given in [mm]. Normally is the load on the wrist of the structure. This value should be correlated to reach. The hint for this option it is a general diagram for correlation between nominal distance and load capacity [17]
Repeatability	Precision of robot on both position and path. It is very important especially in machining and assembly processes
Dimensions and weight	It is not mandatory to be given, but it is recommended if the robot will replace an existing workstation where there is limited space

Thus, the first selections are the application, type of kinematic chain or structure and, eventually the number of axes (Figure 4).



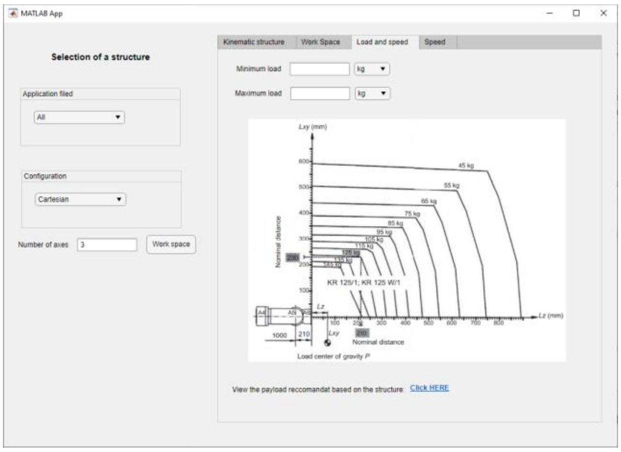
a) Selection of configuration and number of axes   b) Working space for a specific configuration of Cartesian robot

Fig. 4. Input data in selection process

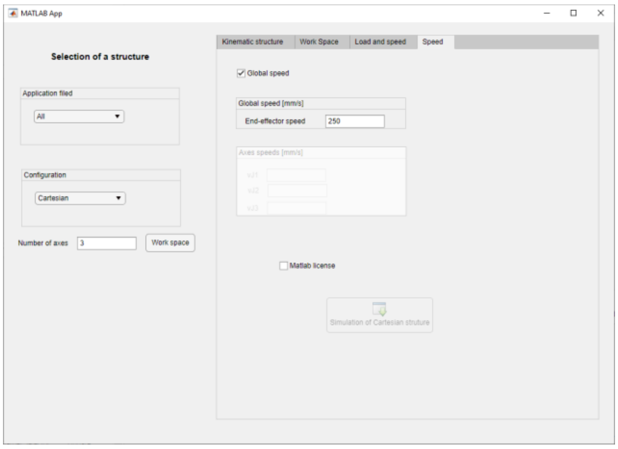
According to the selection from Figure 4a, the needed structure is a Cartesian one, with three axis. The application brings a kinematic drawing of such a structure. There is the possibility to generate the work space (in different area – Figure 4b). The work space is generated based on direct kinematic of the robot based on Denavit-Hartenberg parameters. The modelling of the kinematic is done by using some specific functions developed by the authors for Matlab. Because it is required an individual application with no restriction regarding license of Matlab, these functions were implemented directly in the program.

Besides this, if it is selected the application or the joint' s movement is to big it is suggested to include in structure a fix component along one joint and the values are required (Figure 4b).

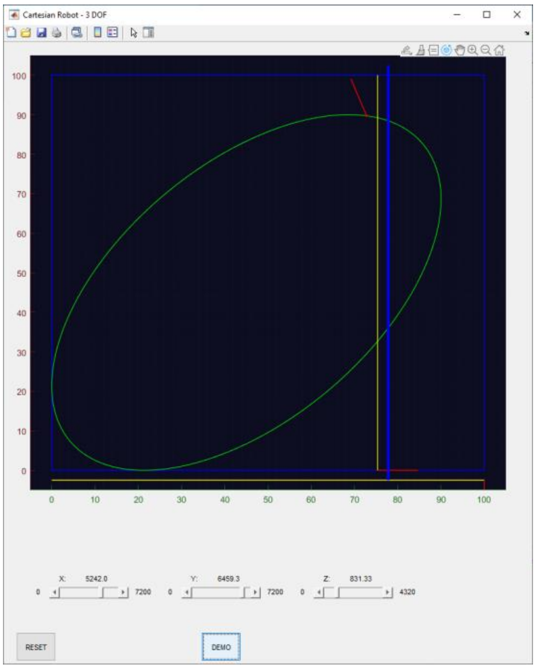
Next step is to specify the load and the speed of the robot. For the load, there are some implicit graphs automatically loaded based on the type of robot (Figure 5a) and there is also given a link to data sheets specific to selected robot. For the speed, there is the possibility of choosing between a global speed (the end-effector speed) and each axes' speed (depending on the specific requirements of workstation). The two options are mutually exclusive (Figure 5b). For those who have Matlab, there is an option to open a simulation (done in Simulink-Simscape) of the selected structure (the input data in the simulation are obtained from the user inputs into application) – similar to one from Figure 5c.



a) Load options



b) Speed options



c) Simulation of a Cartesian 3DOF robot using Simscape

Fig. 5. Input data in selection process

5. Future Work and Conclusion

The modern industry includes industrial robots as the main solution for faster and more accurate production as optimization requirement of manufacturing flows.

However, recent robotic technology are not solving the predictability problem or cost and time optimization problem. Moreover, robots are designed and build to repeatedly and continuously do a given sequence of actions, which make them difficult to reconfigure for a new production line with different properties new product. Besides this, the maintenance is difficult and expensive both because the high cost of components and expertise requirements to replace them and programming.

Industry 4.0, or CPS manufacturing, changes the perspective of robotics from human interaction ability of these kinematic structures. Thus, in the future implementation of such systems, the sensing, communication, decision making should be the criteria of selection robot. As it was presented here, globally there is a grow of collaborative robot.

The application developed it is a tool that helps the user to validate a specific robot, or to validate kinematic and dynamic values need for a specific workstation.

The application should be developed to include more application fields and particularized the existing ones. In the same time there should be included the collaborative robots / corobots and there interaction module.

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