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MECHANICAL ENGINEERING OF ROBOTIC SYSTEMS BY SOLIDWORKS

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Abstract: The modern design studies involve many aspects of product development starting from the concept-zero, continuing with the evaluation and optimization of the structure designed according to many criteria (kinematics, dynamics, strength of materials of mechatronic systems) and ending with specifications for prototype execution. This article evidences design methodologies used in engineering practice in all the design phases, assisted by the professional CAD program, Solidworks.
CAD performances of professional software, by modelling and simulation, contribute to a better evaluation of the research results and to the integration of design into manufacturing phases. These aim to reduce the time from product concept up to it is launched in the market. In the case of robots and complex mechatronic systems, special attention is focused on the mechanical components concept and design so that they enable required motions – trajectory, speed, acceleration. Results of kinematic analysis for two new robotic systems obtained by modelling and simulation using SolidWorks software are presented. There were considered specific phases that are: fully study of requirements; set constraints; concept; 3D CAD model; kinematic analysis; simulation; interpretation of results and conclusion. Finally, relevant benefits of the research for the real case studied are enhanced.
By using professional software for evaluations, it is efficient to make video presentations at an outstanding level which summarizes the evaluation of the studied phenomena and enlightens the research results.
Key words: robotic systems, modelling, simulation, kinematic analysis, SolidWorks software.

1. INTRODUCTION

Product design involves many aspects determined by product application, not only necessary in a particular field of science and in most cases involve multi-disciplinary research. The development of a new product for a complex mechatronic system, involves the use of well-learned methodologies from the practice of design and manufacture, as well as the correct identification of the requirements assigned to that system. For example, if the system is to be used in medical procedures, high attention has to be given to the specific requirements from medicine and interaction with body parts. If the mechatronic system is addressed to people with missing limb disabilities, then attention should be focused on its characteristic components motions and interaction with the existing parts of the body, without neglecting the aesthetic appearance. Specific procedures and rules for its use throughout the life of the product must also be included in the user manual. Methods of maintenance and recycling of the product, also should be included in this user manual.
An aspect related to design performance in the new product development phase is that of the design assisted by high-performance computing technology (IT). The use of electronic computers has strongly boosted the development of new efficient design methods, reducing the time to complete the concept and design phases of the product, prototype execution, product optimization, and then manufacturing of series products. Powerful computing systems with high-speed processors and high-performance of graphic cards have increased user capability through the use of multi-tasking interface systems that allow parallel command execution.
For almost all natural phenomena the evolution can be estimated by mathematical equations described by systems with differential equations [1-2]. The mathematical methods that allow the partial solution of some equations on domains and the final assembly for a complex system allowed the development of methods for solving complex assemblies that would represent idealizations as close as possible to the real model. We mention here the finite and boundary element method, the finite volume method, the extended finite element method (XFEM), etc. Many researchers have developed their own types of finite elements and own improved methods for solving these systems.
Accurate definition of the various efforts (displacements, forces, moments, pre-tensions, temperatures, pressures, speeds or accelerations, etc.)

enables the evaluation of the behaviour of the studied system not only at stationary loads but also transient, dynamic, mechano-thermal, inertial, etc. Today, system evaluation programs allow the input of efforts corresponding to complex phenomena (the behavioural evolution of a system subjected to complex transient phenomenon).

The development of computer interface applications that enable fast communication has also led to the development of performant design methods. The emergence of such applications that are oriented to the 3D representation of the components in an assembly, to the visual definition of how to assemble and how components ineract, has increased the efficiency and attractiveness of engineering design applications. The parallel use of electronic computers for solving the same mathematical problem allowed to solve mathematical systems with very large matrix dimensions (millions of rows and columns) in the case of complex systems. That is why an engineering practice that has gained importance is also concurrent engineering [3-4].

Concurrent engineering is a method of product design and development, in which the various stages in product development are solved simultaneously, rather than iteratively. This method reduces development time and also time to add to the market, leading to improved productivity and reducing costs.

This article evidences methods and results obtained in the research and development of mechatronic systems with medical applications such surgery robotic system for laparoscopic operations or mechatronic systems for upper limb prosthesis. The concept of the systems, their mechanical design, modelling and simulation to validate the components are presented below, highlighting the most efficient use of tools provided to users by the design, calculation and manufacturing (processing) instruments existing in the professional application SOLIDWORKS [5-7].

The use of concurrent engineering methods throughout the design process of a product has not been addressed very often so far due to the difficulties encountered in using multiple programs, and not single software, in the full range of design requirements: design, kinematic evaluation, structural evaluation, prototyping and manufacturing of the physical system (prototype) [8].

API (Application Programming Interface) is an environment support program for Solidworks that allow to write programming commands in a specific language to automate the execution based on procedures implemented internally in Solidworks.

2. THE CURRENT STATE OF ASSISTED ENGINEERING

Many current research concerns the use of dedicated CAD IT applications for systems design. Many applications have also incorporated procedures for assessing assembly tolerances, kinematic motion, structural strength, other phenomena in which the system may be involved (inertial, dynamic, thermal, fluid flow, etc).

The best performing CAD systems today are Catia, Solidworks, Pro-Engineer, Inventor and Ansys. Independent to these CAD applications, there are also many others for structural evaluation based on the finite element method (FEA). Among them, we mention the professional software applications: Abaqus, Ansys, Nastran, Pam-crash, Ls-Dyna, Comsol, Autodesk Simulation. All applications have data entry programs (pre-processing to specify mathematical model). Most finite element programs prove their applicability to parts assemblies in which there is a relatively limited relative motion between parts.

In the case of systems where the components have significant motions (complete rotations, complex trajectories, speeds and accelerations required as loads, etc), there are specific applications for evaluating their kinematics. Among these, the best performing systems are Adams and Solidworks.

Other applications are being developed to implement, test, and verify how to solve mathematical equation systems faster. Among these, we mention: Matlab, Mathematics, Mathcad, etc

The most advanced design methodologies today involve the use of IT applications developed by the user with methods for assembly CAD solutions together with those that validate the system and that allow easy prototyping [9-10].

3. CONCEPT DEVELOPMENT

The concept development, the optimization of proposed solutions, and the choice of the best manufacturing method can be achieved with the help of modern mechanical design tools. Assisted by professional CAD design software, we can get involved in the whole product development process, from the concept phase to the prototyping, evaluation of the structural strength, evaluation of the dynamic behaviour, till effective manufacture by choosing the methods of physical execution and final assembling.

4. CASE STUDIES

This article presents two different models of mechatronic systems whose engineering stages were aided by SolidWorks software (see figure, 1 a. and b.):

a. parallel robot with Gough-Stewart configuration

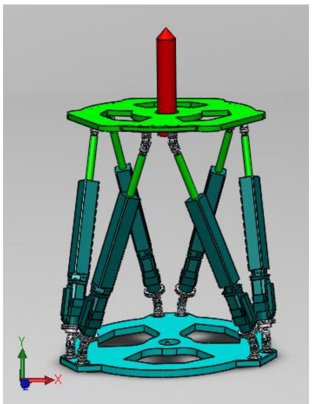
b. finger of hand prosthesis prototype.

4.1. Evaluation of workspace

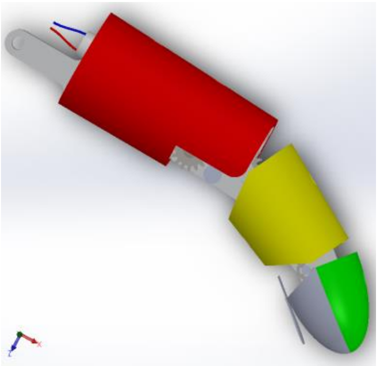
The space limits within robotic systems' components are able to perform motions are usually established initially when the concept is defined. The final limits toward the robot can move to, must have defined the initial limits imposed. All the space in between the initial and final motion limits is called the robot workspace. Moving out of the possible workspace involves moving the reference system, so that the robot should gain mobility. This is done by moving the base either manually within certain limits after the system must be fixed again before actuation, or using a second robotic system.

Evaluation of the robot's workspace is as complex as the robot configuration is.

This is why, a method for evaluating the workspace by Solidworks API is evidenced next. It is an application of the method developed in [11] which follows the boundary of a workspace at actuators limits of a robot with a parallel configuration. A quarter from workspace is shown in figure 2.



a. Stewart parallel robotic system



b. index finger of hand prosthesis

Fig. 1. Robotic systems – case studies.

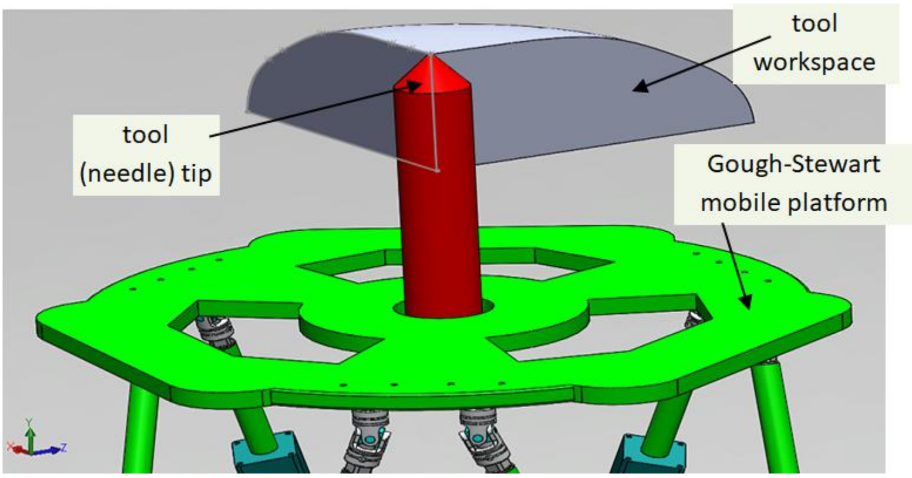


Fig. 2. 3D Workspace generated with Solidworks-API.

4.2. Optimizing the concept for required trajectories

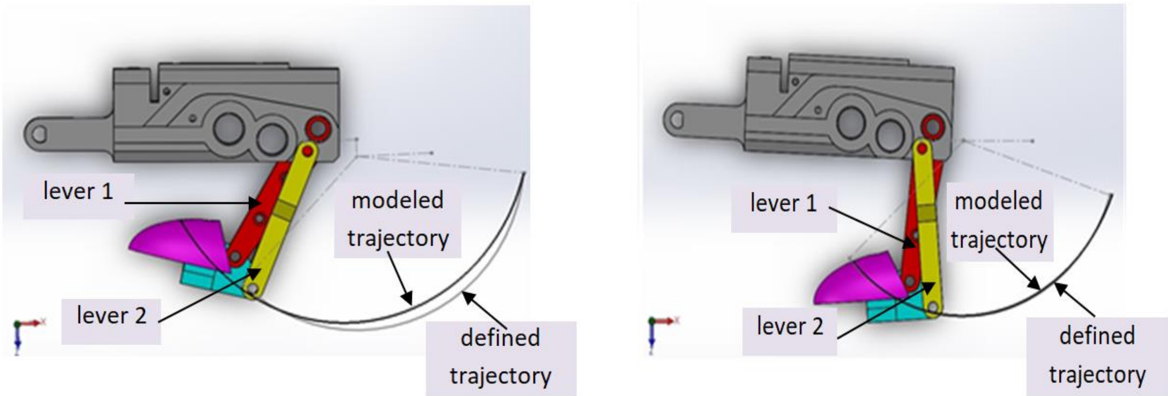
Another method for design optimization implies optimizing of the configuration of a robot when the optimization function is described by variables that are related to the kinematic characteristics of the system (trajectory, speed, acceleration).

In this case study is presented a method for optimizing the kinematic configuration of the index finger hand prosthesis [12, 13], considered as a serial robot. The criterion used in optimization is that of minimizing the deviation from a defined trajectory. In figure 3 a. and b. there are presented three successive positions of the index finger.

The real motion and trajectory of the fingertip is described by circle of 64 mm diameter. In order to obtain this, there had to be adjustments to dimensions of the 3D model (lever 1 and lever 2), more than 20 iterations in modelling, so that finally, the defined trajectory to be obtained (figure 4 a. and b.). The curve in grey colour represents the defined trajectory and the black colour curve stands for the trajectory of the 3D model fingertip.

a.real index finger

b.index finger prototype
Fig. 3. Index fingertip motion.



a. first iteration, different defined and modeled trajectories

b. final iteration, identical defined and modeled trajectories

Fig. 4. Design optimization by defined trajectory criterion.

4.3. Kinematic optimization based on path planning strategy

The evaluation of the robot behaviour and of the methods to control a mechatronic system along to a required trajectory involves both the kinematic and the dynamic evaluation when moving into the workspace. The path planning aims to control the actuators to perform necessary motion of the robot end effector. For the case study considered in this paper (parallel robot with Gough-Stewart configuration) it is the tip of the tool fixed on the top of the mobile platform (see figure 2).

Exceeding the allowable load values on the actuators leads to the locking of the mechanism. In the real case, in addition to the difficulties and restrictions due to the kinematic configuration, there are also difficulties related to tolerances, friction in joints, positioning errors, etc [14].

In this research case there is implemented a method for optimization of a trajectory of the working tool, for a parallel robot with Stewart configuration. The deviations from the trajectory should not exceed 10 mm. The objective function was to minimize acceleration.

Two types of path planning optimization methods have been implemented, as mentioned next.

a) A classic method with sequential optimization based on fixed step, which involves modifications of the connecting radii of the trajectory curves for an imposed path in the 3D space;

b) The second method uses a genetic algorithm implemented directly in the Solidwork API to select the best spline curve that meets the above requirement.

A spline is a special function defined using piecewise by polynomials where curve has continuity in tangency at knots.

In problems with interpolation, spline is often preferred then other functions because it yields

similar results, even when using low degree polynomials.
By Solidworks, the optimization of functions that are related to the result of studies can be done also in external programs (own sources of compiled programs or programs that allow mathematical calculations – for ex: Matlab), if they are controlled directly by the Solidworks API, but in this case, a clear delimitation must be made between the internal variables and those from the external program [14-15].

Figure 5 shows the acceleration function when moving the tool along the entire path for the last 3 steps from optimization method A, renamed here as step-1, 2, and 3.
In figure 6 is presented the acceleration function while moving the tool along the entire path only for the last step from optimization method B, method that use a genetic algorithm implemented direct in Solidworks-API to modify the location of the knots that define spline function of the path trace.

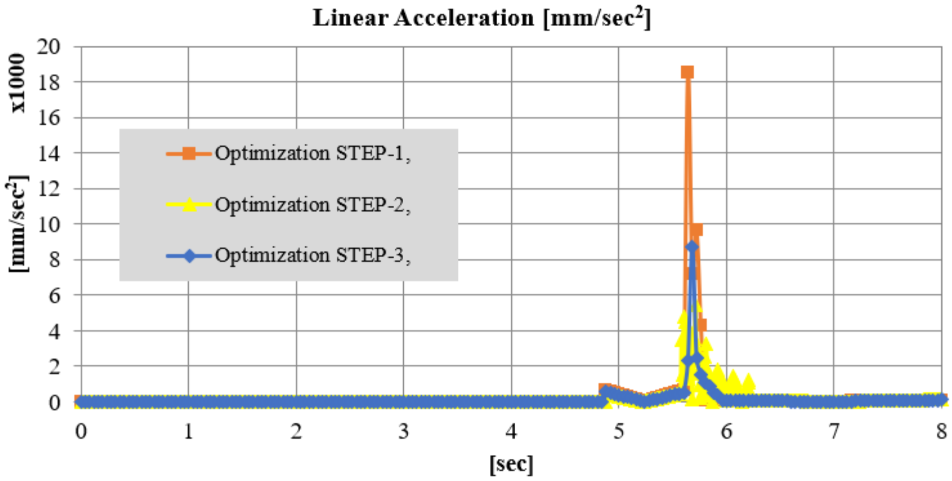


Fig. 5. Linear acceleration magnitude during movement measured at tools location using method, A for optimization.

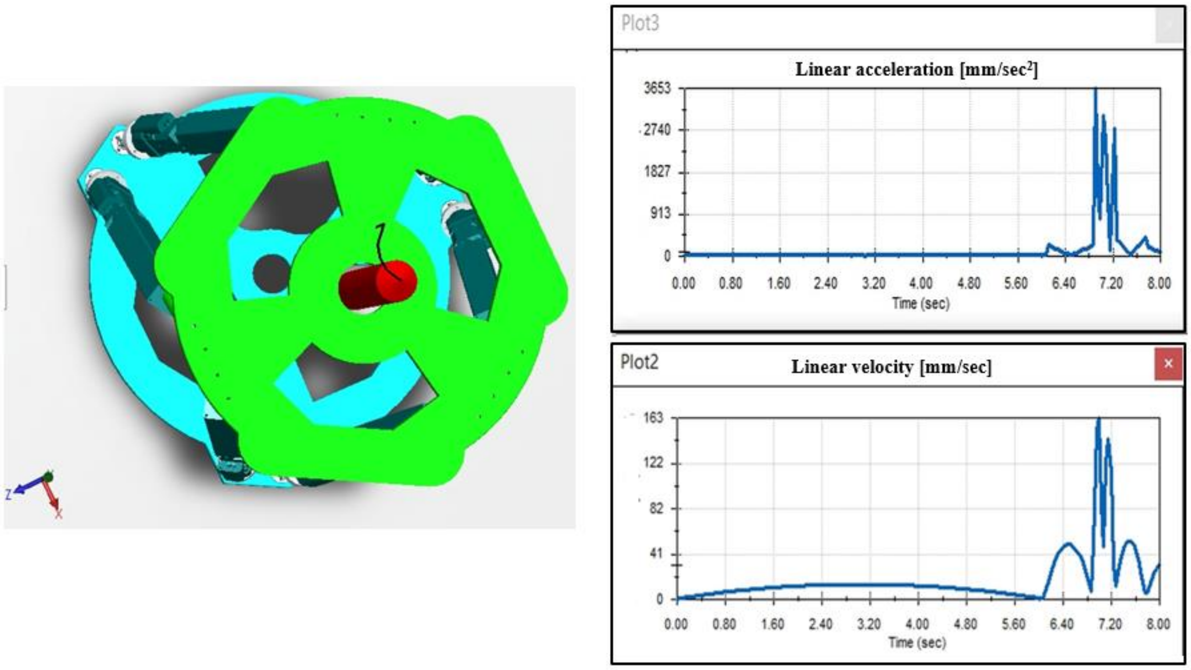


Fig. 6. Linear acceleration magnitude during movement measured at tools location using method B for optimization – final step.

4.4.Topological optimization

Topological optimization refers to the implementation of methods for optimizing the parts shape of an assembly, so that to meet all the requirements of a rigorous design: the criteria for structural strength, reducing the mass of components, choosing the most appropriate shape of components, choosing the best materials, etc. [16].
This research studied case was focused on the improvement of parts so that ensures optimum

weight, material and stress at specific load cases. The topology changes are aimed at making cuts according to a specific pattern adapted to the parts and the introduction of ribs to reduce mechanical stresses (see figure 7).

4.5. Prototyping strategy

The use of 3D printers has brought benefits in rapid manufacturing of the first prototypes and even of the final assemblies. Choosing the right technique and, therefore, the rough material (either as plastic filament, powder, or resins) to be used for the prototype involves specific advantages and disadvantages. Considering also CNC machining is sometimes the best choice in prototyping high precision parts (see figure 8 a. and b.).

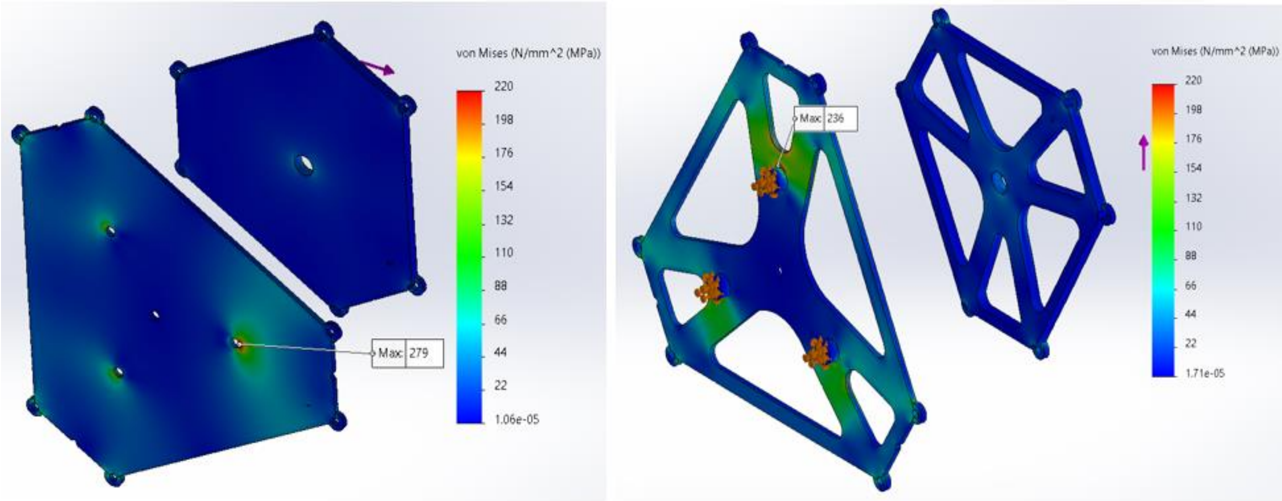
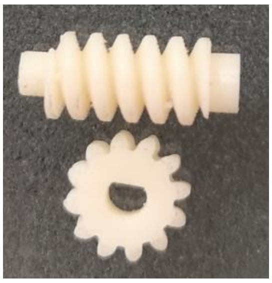


Fig. 7. Topologic optimization from the initial model (left) to the design from right side based on multiple criteria: weigth, material, maximum stress.



3D printed

worm machined on CNC lathe for correct worm gear

a. hole reaming required after 3D prototyping

b. prototypes of worm gear

Fig. 8. Prototyping components of index finger.

Decision for the best execution methods can be implemented and verified in the CAD Solidworks application by its specific tools adapted to the execution processes on 3D printers or CNCs.

4.6 Automate the process of making product documentation

Any design product (project, prototype, or final product) must be accompanied by appropriate documentation that contains as much information as possible about all components of the assembly. This documentation can be done automatically with the help of the professional design software Solidworks, if the necessary information is given into the project. Such product specification may include information about how to assemble, how to make each component, the list of components that should be purchased from external suppliers, their prices - regardless of whether it is purchased elsewhere or made in our workshop (raw material costs, manufacturing technology costs depending on the complexity of the part, etc.), choice of assembly tolerances, execution drawings for each component and sub-assembly, use and evaluation of advantages in the use of flexible configuration, useful information for the end-user about how is presented and how to use the product, information about how to handle errors, information about product recycling, etc.

4.7 Fully automatically build of CAD assemblies

On top of all these advanced design methods, an idea about fully automated methodology for making a whole set of parts is presented below. By using the Solidworks program together with the corresponding API language, a whole assembly can be obtained automatically, based on the definition of the concept and parameterizing the components, by the predefined way of assembling the pieces, and following clear criteria for making the product.

The flexible use of part configurations can be used to develop new products with new dimensions, for another range of mechanical characteristics (speed, acceleration, workspace, etc.) and new operating tasks (masses, loadings, mechanical work and working power, etc)

In figure 9 is presented a 3D assembly completely build using only API programming inside Solidwork using a specific user-GUI (interface and programming commands).

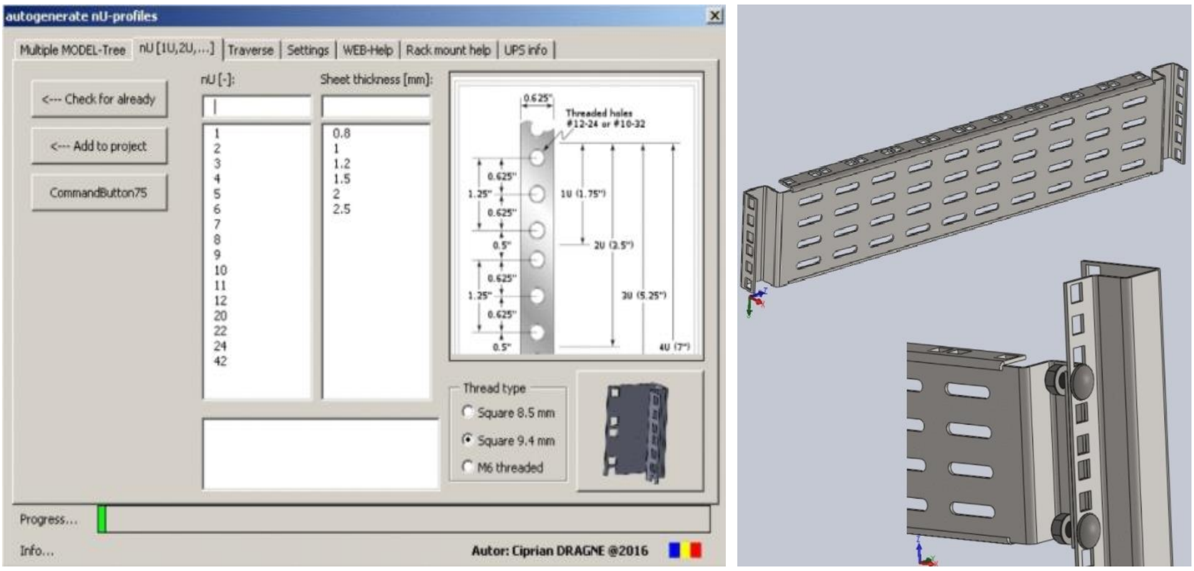


Fig. 9. Fully automatically build parts and assemblies in Solidworks-API.

5. CONCLUSIONS

Using modern CAD design tools can bring many benefits to its users. Solidworks is a design program for engineers and with many capabilities. Initially compiled for visualization and virtually build of the complex assemblies that involve precise definition and many parts with various shapes in 3D space, the program has developed in recent years in a complex program to assess assembly tolerances, kinematics, structural strength, the way of product execution, parameterization and development of new products starting from already existing projects, evaluation of manufacturing, etc. All of these phases from the product design study and up to product prototyping and / or manufacturing could be solved with a single working tool, the Solidworks software.

Technical conclusions:

Study case no.1, error from the imposed path for final design was less then 0.5 mm

Study case no.2, using sequential optimization was obtained a path trace that reduce acceleration during movement up to 6000 mm/s^2. Using GA to control knot locations of a spline curve it was obtained the value of 3653 mm/s^2, for maximum acceleration.

By trying to put everything together we can obtain a complete program for mechanical design, with all necessary procedures implemented according to our needs and with an attractive GUI (graphic user interface). Of course, all these procedures need a force tasking at user's knowledge in engineering processes, programing skills, or manufacturing capabilities.

Complete task of the simulations was developed based on Matlab software [17], Solidworks professional [18] and user defined programming routines [19].

Knowledge level will be evaluated into the future by more criteria with performances in using computers. Computer aided design and technology became more complex, more global in all aspects of product manufacturing, smarter in decisions

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