Chapter

New Trends in Robots Engineering with Professional Software SolidWorks

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Abstract

Engineering robotic systems stand for a challenging complex process, closely related to product development phases. Society's needs and requirements generate the idea for new robot products, which are sketched as an initial concept. This is the moment when the design phases start, engineers continue their work by evaluating and optimizing the mechanical parts according to many criteria: kinematics, dynamics, the strength of materials, NVH, thermal assessments, etc. Finally, there are established specifications for prototype execution, environment sustainability, end-user specifications, and recycling requirements. All these phases could be implemented into smart software. SolidWorks is such software enabling the creation of new mechanical designs automatically based on its programming tools. This chapter is focused on relevant advanced capabilities of SolidWorks software to assist engineers in achieving a new advanced level in mechanical design, that of automatically generating new or modifying existing concepts according to the requirements. By using professional software in research studies, new engineering procedures can be developed in order to automate the concept and design phases for many concurrent engineering methodologies, design optimization methods, manufacturing, documentation, or end-user specification. Case studies on the different types of robot systems used in healthcare and assisted living are presented.

Keywords: robots, mechatronic system, optimization, concurrent engineering, Solidworks, healthcare, assisted living

1. Introduction

In any concept of a robotic system, the start is with a vision of the product, and an idea to design. As soon as the work for it begins, the project outline and preliminary calculations to evaluate the concept are to be done. These could involve calculi for evaluating the kinematic performance, the working space, evaluating the loads during operation, evaluating the type of materials used, calculation of components' pre-sizing after a few significant simulation cases, calculations of the product life and cost calculations [1].

After these preliminary phases, next step is that of detailed design. Building of a detailed 3D model, kinematic evaluation of the system, strength calculations for all required cases, evaluation calculations according to other criteria, steps for optimizing components that do not meet the needed requirements, durability calculations, and service life assessment of components - all of these represent bases of a complex engineering process [2].

Both preliminary and detailed calculation cases are multidisciplinary assessments. These may include both strength analysis and assessments of dynamic behavior, thermal effect, interaction with substances that require an assessment of fluid flow, etc.).

This chapter, gives an overview of some practical methods of product design, following all the aspects mentioned above, but using modern methods and a professional CAD program. The use of modern methods means the use of personal computers both for the evaluation by already set methods and for the development of new methods, which bring to a new light all the features evaluated by older methods [3].

Finally, it is to be enlightened that the use of advanced CAD programs could enable, even “extravagant” facility such as the automatic realization of components, the evaluation of many features under the perceptions of competitive engineering, and even the automatic elaboration of projects, drawings, and technical specifications of a product [4].

Concurrent engineering is a method of designing, evaluating, and developing a product, in which the various stages of its evolution are solved simultaneously, rather than iteratively. This method reduces the time of design, implementation in production, the time required to launch onto the market, etc., which leads to improved productivity and reduce costs [5–6].

Mechanical design of mechatronic system's components, modeling and simulation for further validation are presented next, highlighting the most efficient use of design, analysis, and manufacturing tools offered to users by SOLIDWORKS.

2. Current state in design

In the early days of engineering, designers used empirical, sequential, uni-criteria methods. All those methods were executed most of them on paper, and the project files included explanations of all the required phases and calculation steps. The need for faster evaluation methods has even necessitated the advent of calculating machines. At first, computers were not programmable, the commands were executed line by line, and so were the results. With the advent of programmable computing tools, the earlier stages of product development have been completed more quickly and new methods have been developed and diversified. Thus appeared the first dedicated computing programs. In fact, the first programs were developed even for engineering purpose of calculating some parameters that required long time of information processing. One of these areas was the methodology for calculating a trajectory required for a space shuttle, taking into account all the factors that influence this trajectory [7–10].

Over time, software for complex mathematical calculations have emerged. Some of these programs are MATLAB and Mathematica. These allow to introduce command sequences to evaluate mathematical expressions.

At the beginning, most function evaluations were performed in simplified representation systems, with variations of curves only in plane. Thus appeared the first CAD programs (for the graphical representation of the components) but they showed the pieces only in 2D representation.

However, the components encountered in reality are three-dimensional. The whole visible universe unfolds in a huge 3D scene. The emergence of components representation as three-dimensional structures seems a natural step in the development of design software.

According to the main purpose, the design phases of a product can be divided into:

- evaluation phases of the assembly of parts and subassemblies;
- phases for analyzing the stress and strain state of the components or, the strengths of the whole assembly (as a structure);
- phases of making the documentation;
- execution phases of the parts;
- execution of prototype;
- phases of experimental tests;
- phases of entry into production.

Each of the above phases has acquired well-known names over time, as mentioned next.

- Modeling the geometry and the way of assembling the system components has been called CAD (computer-aided design);
- Carrying out the structural evaluation phases and the characteristics of the product has been called CAE (computer-aided engineering);
- Carrying out the execution phases of the product has been called CAM (computer-aided manufacturing).

If in the beginning, CAD-CAE-CAM programs were clearly differentiated from each other, in recent years there has been a trend of unification, so software developers have begun to unite to bring out more and more high-performance engineering applications. CAD developers today seek to benefit from the performance of subassembly calculation and evaluation programs, while CAE application developers seek to benefit from the performance of CAD applications for viewing complex 3D assemblies. One of the three areas has lagged behind in recent years. This is the realm of CAM applications. It was only after the advent of CNCs that a clear connection with the above applications was achieved. The ultimate goal of any product is its physical realization. It is obvious that the methods of physical realization can influence all the previous methods of design, going back even to the initial conception and idea phase.

The most advanced 3D geometry modeling applications today are Catia, Solidworks, Pro-Engineer, Inventor, and Ansys. There are also others, many are developed ad hoc in various universities around the world.

As mentioned above, the methods for evaluating the performance of systems were initially developed separately from the CAD part, although applications of materials strength methods have gone hand in hand with engineering from the beginning. In any kind of concept, the engineer had to have knowledge about the possible tasks that could be supported by the designed structure. A very common method used in recent years to evaluate the performance and mechanical properties of a structure is the finite element method (FEA). The most advanced professional applications in these methods are Abaqus, Ansys, Nastran, Pam-crash, Ls-Dyna, Solidworks, Comsol, Autodesk Simulation, etc. [11–16].

A special field of research derived from evaluating the performance of a system is studying its kinematics. Establishing and evaluating the performance of a system in all positions of the workspace, including the determination of displacements, speeds, and accelerations in the system, proved necessary in the study of its dynamics. In the case of systems where the components have relative movements with respect to each other (complete rotations, complex trajectories, necessary speeds and accelerations as tasks, etc.), specific applications have also appeared for the evaluation of their kinematics. Relevant ones, as best performing applications, are Adams and Solidworks.

The development of ideas and concepts, the assembly of designed components, the evaluation of performance of the whole system, the optimization of the proposed solutions, and the choice of the best manufacturing method could be achieved with the help of modern mechanical design tools. Engineers, assisted by professional CAD-CAE-CAM design applications, could be involved in the entire product development process, from concept phase to prototyping, structural strength assessment, dynamic behavior assessment, effective manufacturing by choosing execution methods of physical and final assembly, as well as completion of all product documentation including maintenance and recycling phases.

3. Concept development

Basic aspects of concept development for different robot/mechatronic systems are presented next.

3.1 Concept of robot for laparoscopic surgery

This subchapter presents the concept of a surgical robot, designed in a kinematic chain configuration with parallel components. The medical purpose is that of surgical robot usable in brachytherapy procedures.

The development of the concept from the idea to the detailed CAD model for the surgical robotic system went through the following stages:

- establishing the preliminary dimensions;
- establishing the first configurations;

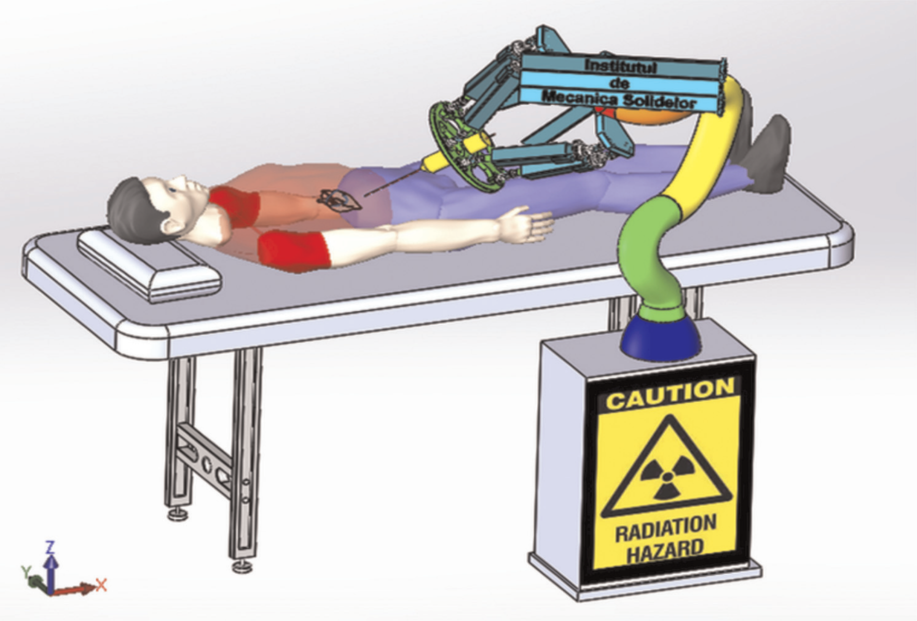


Figure 1.
Surgical robot - CAD model.

- optimization of the first configurations for kinematic performance parameters, the workspace, the optimal trajectories, the kinetic parameters, etc.;
- selection of components for acquisition, actuators type;
- structural optimization based on the criteria of mechanical strength, selection of the best materials, assessment of NVH behavior and thermal effects, etc.;
- establishing the optimal locations for the acceleration sensors intended to monitor the structure;
- evaluation of the product life;
- mechatronic system control strategy - choosing the programming platform for control functions;
- choosing the built strategies of the parts;
- evaluating the costs of the product.

The (up to date) model of the robot for laparoscopic surgery is presented in **Figure 1**.

3.2 Concept of mechatronic system for visually impaired people

This subchapter presents the concept of a modular mechatronic system for visually impaired people. The idea of the concept came after studying the assistive devices present on the market, and the conclusion that they can be improved. This concept aims both to address the issue of assistive devices for the visually impaired and to present a virtual prototype of a modular mechatronic system for visually impaired

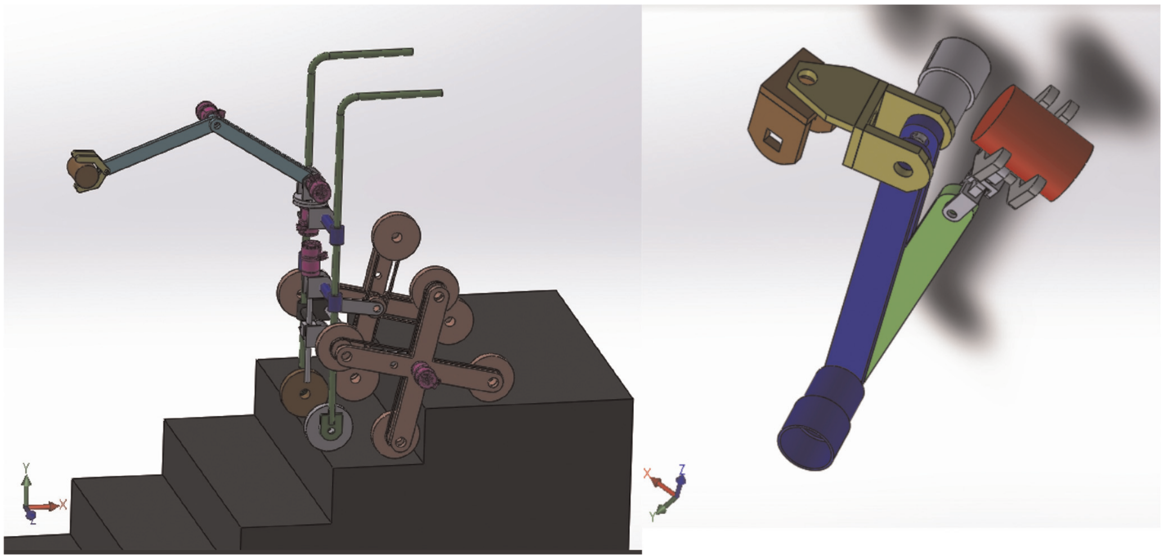


Figure 2.
Visualy impaired mechatronic system - CAD model. (a) whole mechatronic system (b) robotic arm sub-system.

people who have acquired other mild or medium deficiencies during life or even from birth. The virtual prototype is not a prototype for a conventional device, but a custom one consisting of modules that can be added as the person has adapted to the basic set and other needs have been identified. The prototype of the mechatronic system contains multiple modular systems (location, color identification, object bypass, haptic feedback - audio, and others). People with visual impairments, in addition to having to move in closed or open spaces, need to carry out daily activities which, in most cases, require the recognition of objects in the environment.

The mechatronic system is designed so that people with mild neuro-motor dysfunctions could also be helped to move, to go up and down stairs and the robotic arm to help the blind person when there is a window on the taxiway, as well as doors from open cabinets to push them.

This system is intended to help the visually impaired in difficult times for them, such as bypassing obstacles in the way. The user in the situation when will use it in open spaces will face all kinds of situations that he has to manage.

From the mechatronic point of view, the system's basic components are (see **Figure 2**):

- the motion system – with wheels enabling climbing up/down stairs;
- the robotic arm system - will push window handles, open cabinet doors that stand in the way of the subject, grab objects from shelves, etc.

3.3 Concept of anthropomorphic walking robot foot

Anthropomorphic walking robots are extremely complex systems whose main problem is static and dynamic stability in the unknown environment. In most cases, the fulfillment on the tasks depends on:

- mobility of mechanical structures;

- identification and recognition of objects and obstacles;
- navigation in the workspace.

Figure 3 (a) shows an innovative 3D solution in terms of mechanical structure, which is generated by the SolidWorks software. The idea was to design a walking subsystem for anthropomorphic robots that provides increased mobility and energy efficiency for effectors movements. It was chosen the version with sole consisting of three segments to ensure the extra force of movement through the toes and articulated heel for increased cushioning on contact with the support surface. The building blocks, both mechanical and electronic, are mostly chosen from SolidWorks' database.

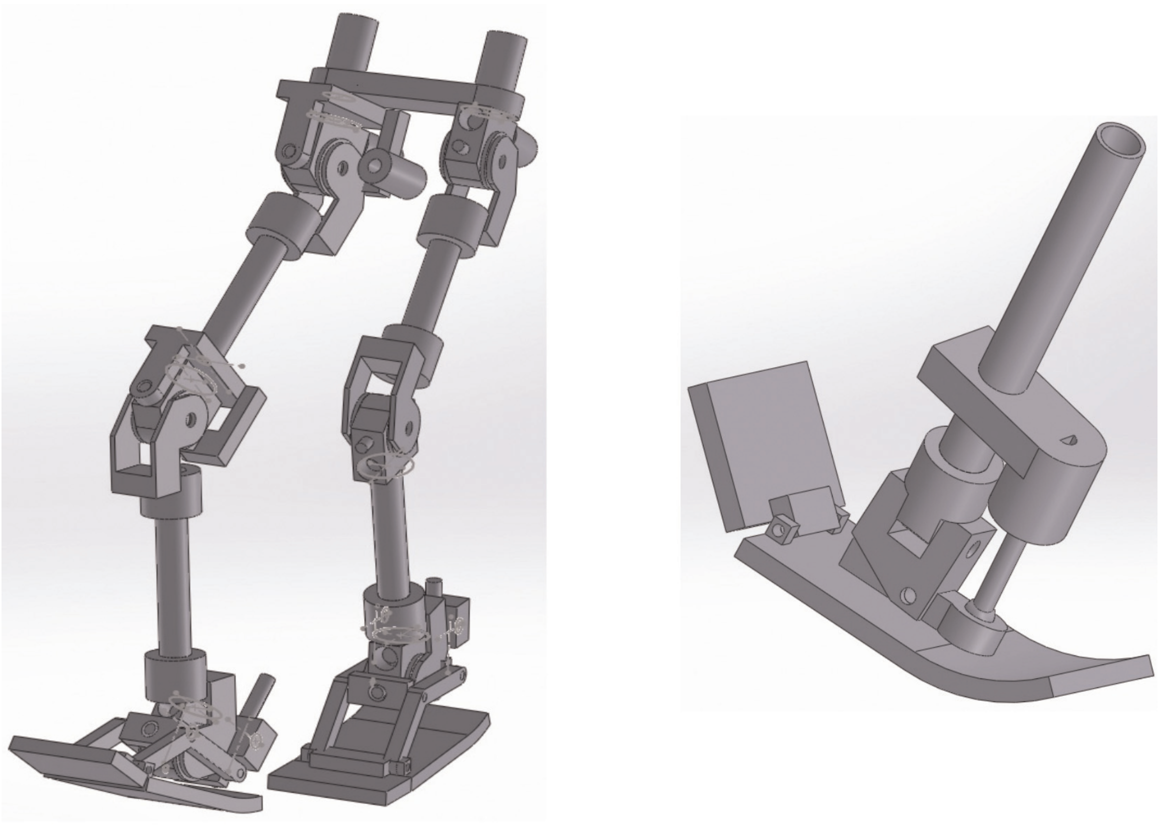
Figure 3 (b) shows the 3D solution of the anthropomorphic robot sole with articulated heel generated by the SolidWorks software.

The dimensions and characteristics of the designed mechanical elements are component parts of the control law that guide the heel when it lands on the support surface.

The physical parameter defines the rotation of the heel for shock cushioning is as follows (Eq. (1)):

$$I_p = I_e \times \left[1 + F(t_i) \times \mathscr{S}/\left(k_m^2 + k_g^2\right)^{1/2}\right] \tag{1}$$

where I_p is the weighted inclination of the normal point of contact of the heel relative to the vertical position, I_e is the estimated inclination by calculation of the normal point of contact of the heel relative to the vertical position, $F(t_i)$ is the force on



(a) (b)

Figure 3.
Mechatronic system for antrophomorphic robot foot. (a) General scheme (b) Sole detail.

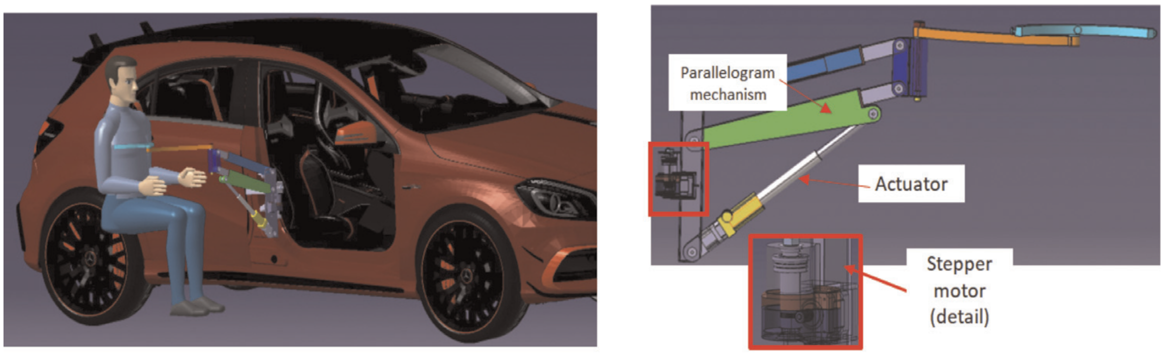
the support surface at the moment t_i, δ is the damping displacement, k_m and k_g being the rigidities of the material, the heel of the foot and support surface, respectively.

From the point of view of the motors used, we chose the brushless DC version, in order to have a fast, precise movement and a clearly superior control of the position of the robot's legs segments.

3.4 Concept of mechatronic system for locomotors disabled people

The mechatronic system's concept presented in this subchapter is aimed to help people with disabilities, people who present different forms of paralysis of the lower limbs, or simply those who are in a period of medical recovery after undergoing operations that restrict their mobility. By the system (see **Figure 4**), these people are assisted in in transferring from the wheelchair to a vehicle or in performing various household activities.

The transfer from a wheelchair to a vehicle is the operation with a high degree of difficulty, because the person's loading area is limited, the movements of the system are limited and the possibility that the system or, worse, the person, will collide with car parts (door, pillar, chassis) is high. The system can be adapted on several types of vehicles depending on the car geometry (pillar shape and dimensions), as its concept is that of adjustable clamping hinge (see **Figure 5**).



(a) (b)

Figure 4.
Mechatronic system for locomotors disabled. (a) transferring to car front seat (b) paralellogram system.

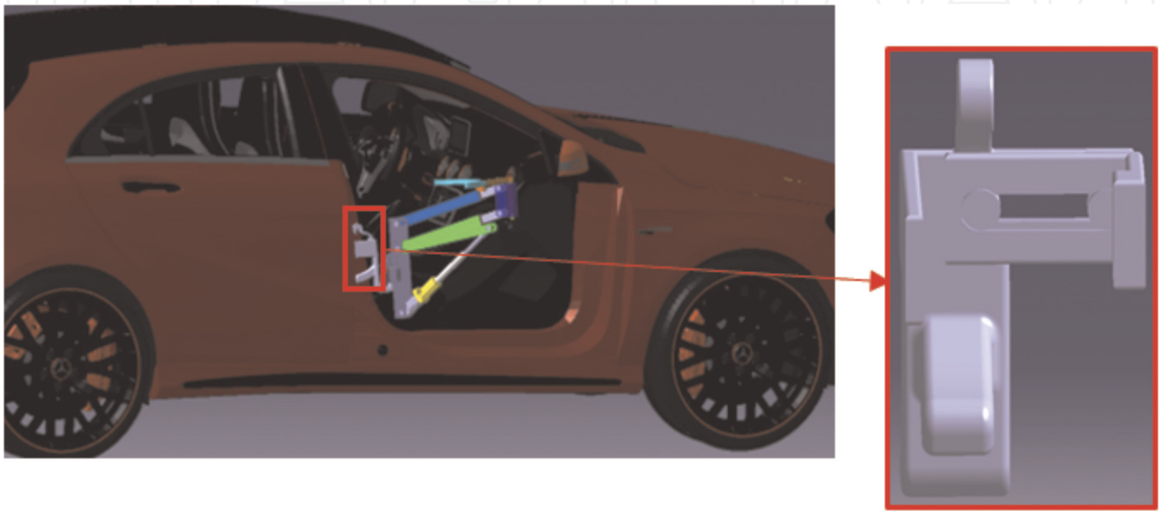


Figure 5.
Adjustable clamping hinge.

4. Case studies for robots systems engineered assisted by professional SolidWorks

Robots and mechatronic systems' engineering using professional SolidWorks is relevant in any stage of new product development. Some case studies for the designed systems are shown next.

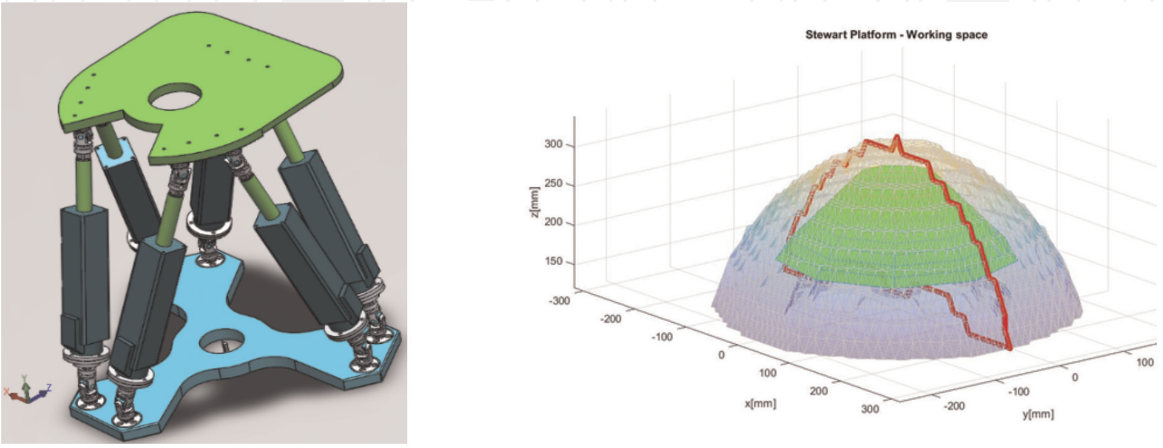
4.1 Analysis of robot for laparoscopic surgery

A surgical robot needs very well-prepared documentation that includes many chapters about:

- the medical procedures considered;
- the main requirements of the medical robot: workspace, used tools;
- the mechanical characteristics required or to be taken into account;
- kinematic, dynamic, medical imaging performances, etc.;
- materials used, medical instruments;
- the maintenance specification of a product that works in the medical field;
- recycling conditions.

4.1.1 Workspace

The workspace is the entire space around the "home" position where the robot can move. This is the robot workspace. The evaluation of the workspace is done by knowing the direct kinematics equations for a robot with configuration based on parallel structures (see **Figure 6**). Such workspace is presented in gray color in **Figure 6**-b with a section in red color. But near this workspace should be added the



(a) (b)

Figure 6.
Workspace of hexapod robot. (a) hexapod robot (b) robot and required workspace.

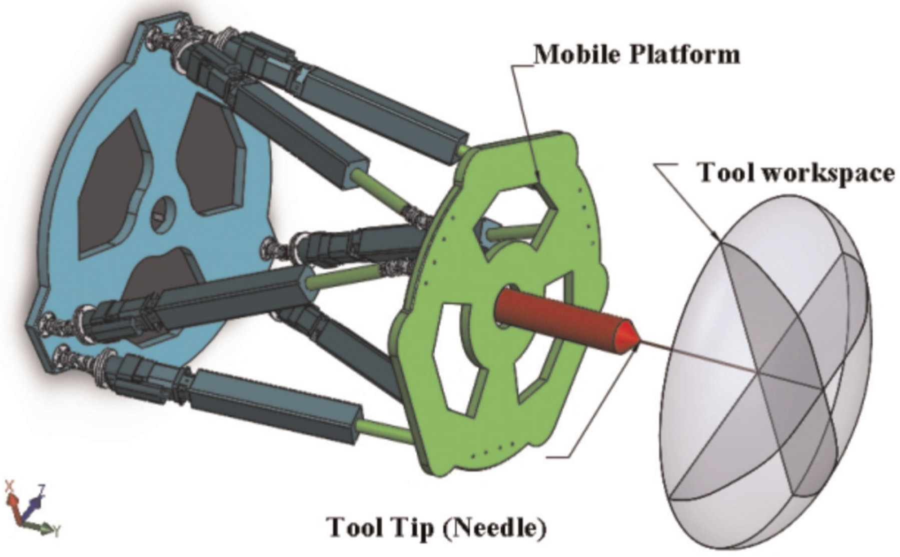


Figure 7.
Robot workspace evaluated with Solidworks API.

required space on design. This space is presented in green color, which is a special workspace in the sense that its definition is made in cylindrical coordinates. This type of workspace has a number of advantages in terms of solution symmetry and the disadvantage that the implementation of its equations is complex.

The workspaces above were evaluated using the MATLAB program based on a parametrization in the position of the platform using only generalized displacement at its center. These mathematical equations can also be implemented in a CAD program in order to benefit from all its graphical performance. A such example is in **Figure 7**, which shows the workspace of a hexapod robot evaluated using procedures developed with the Solidworks API. The working method uses the procedures presented in [17] to find the boundary of the workspace at the operating limit of the actuators.

API (Application Programming Interface) is a background support program from Solidworks CAD that allows programming commands to be written in a specific language to automate model execution based on procedures implemented internally in software.

The methods presented for a robot's workspace do not take into account the possible collision between the elements of the system when positioning in workspace. Because the actual geometry of the components can vary greatly from the idealized shape, then it is necessary to implement collision detection procedures.

4.1.2 Collision detection

A robot is generally a machine designed to perform tasks automatically, with speed and accuracy. Even when a robot is operating properly, it may collide with people or objects that enter its workspace and may even cause personal injury or damage to those objects. A particular case is the self-collision when the robot strikes its own components from which it is built [18, 19].

Injuries or damage to others (humans or mechanical components) due to the robot's activities are classified as contact damage. The main aspect of the impact between two or more components is collision detection. How collision assessment depends mainly on the geometry of the parts, the more complicated are the components, then more

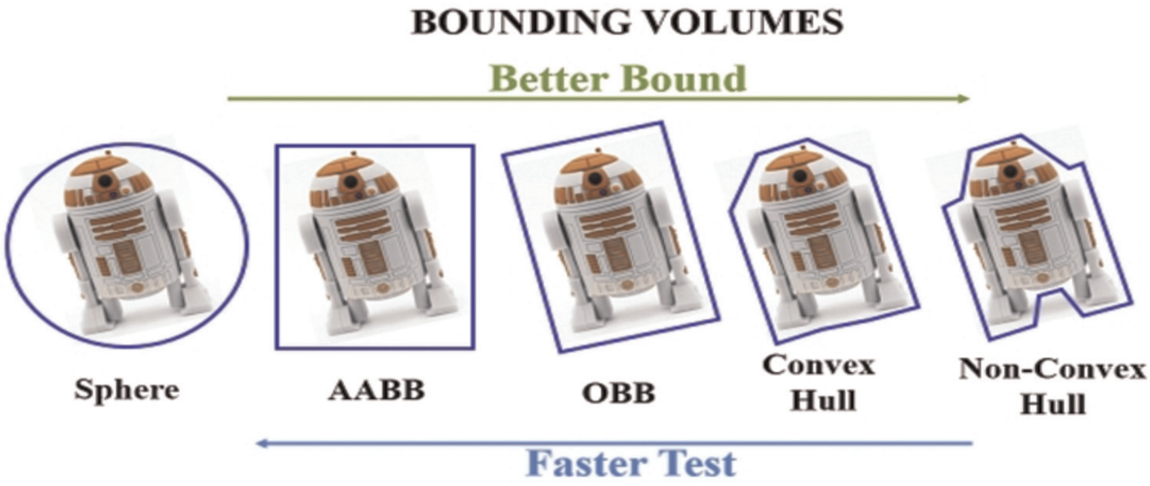


Figure 8.
A short presentation of decomposition techniques used in collision detection [20].

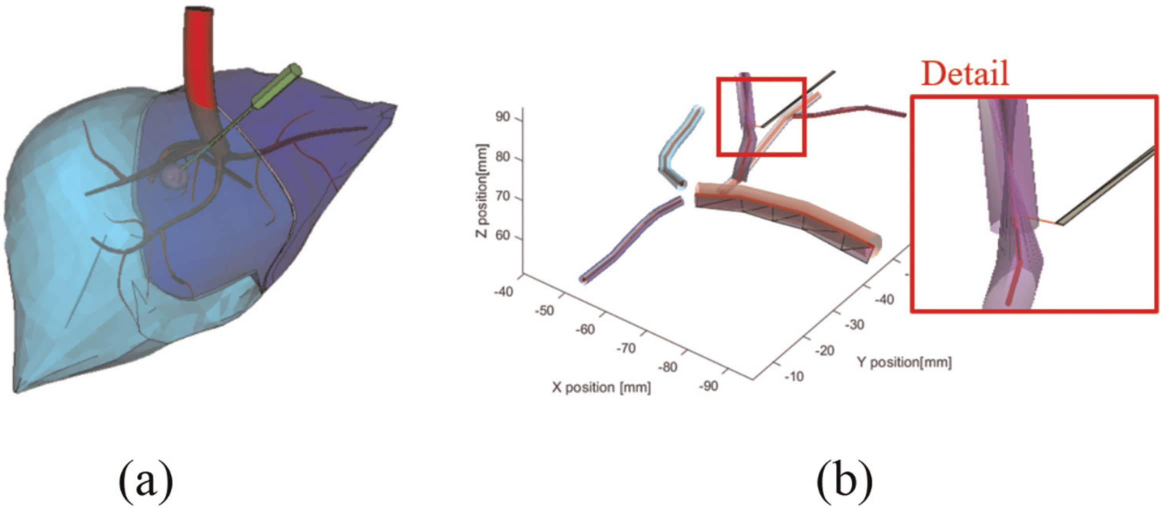


Figure 9.
Collision detection strategy at forbiden zones. (a) virtual reprezentation of liver (b) veno-arterial tree in tubes geometric primitives.

time it takes to assess possible collisions. That's why it's a good idea to start with a simplified geometry. **Figure 8** summarizes the geometry decomposition techniques used in collision detection. In paper [20], the authors presented some innovative techniques for the detection of collisions between components with complex geometry.

If the assessment of the collision is done with a veno-arterial network then the detection becomes even more complicated. For the speed of the calculations, it is recommended to simplify an artery tree until to the level of geometric primitives (**Figure 9**).

The Solidworks software is useful in collision detection with its methods to evaluate the distance between components.

4.1.3 Kinematic performances

Evaluating the configuration of a robot involves a study of choosing the best features (dimensions, types of links, type of drives, etc.) according to different criteria, such as:

- compatibility with the surgery room and with medical procedures;
- compatibility between the tools used and the workspace;
- compatibility with the kinematic performances of the robot.

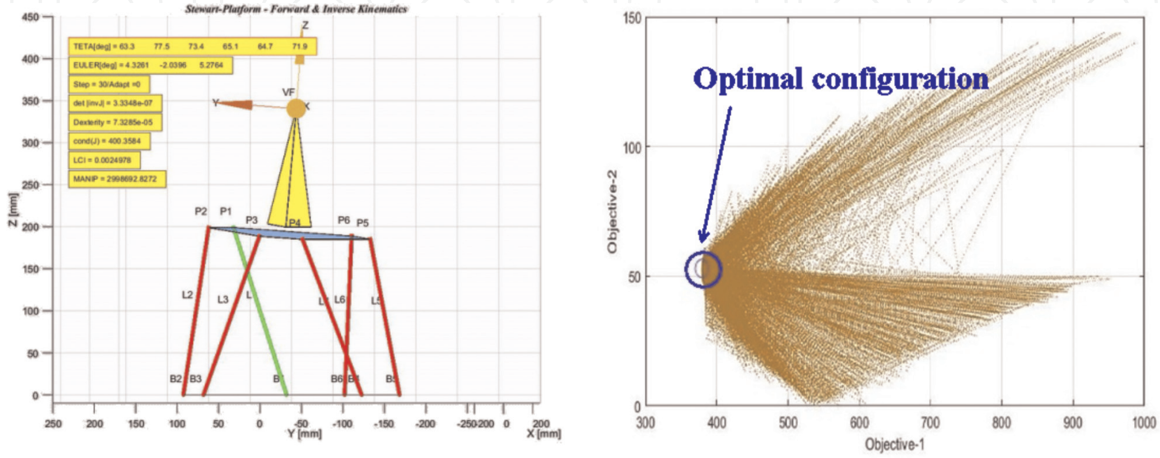
The optimization of the different quality parameters of the robot must be done according to several kinematic performance criteria (see **Table 1**): singularities, determinants of the inverse of the Jacobian matrix, dexterity, global conditioning index, local conditioning index, manipulability, etc. [21, 22].

Optimization of configuration (see **Figure 10**) involves the knowledge and use of advanced methods of mathematical calculation: multi-criteria methods, genetic algorithms (GA), and matrix processing. **Figure 10**-b shows the dispersion of intermediate results when using a GA to optimize the configuration of a hexapod robot until the optimal position is found.

The kinematic evaluation of the mechanisms can also be done using a professional CAD program. Solidworks provides tools for such assessments. **Figure 11** shows the final results of the positions of a surgical robot using the Solidworks software for both the forward and inverse kinematics. **Figure 11**-a shows the results of forwarding kinematics procedures by increasing the length only at one actuator, and **Figure 11**-b shows the results of inverse kinematics procedures to put the tools at a specific

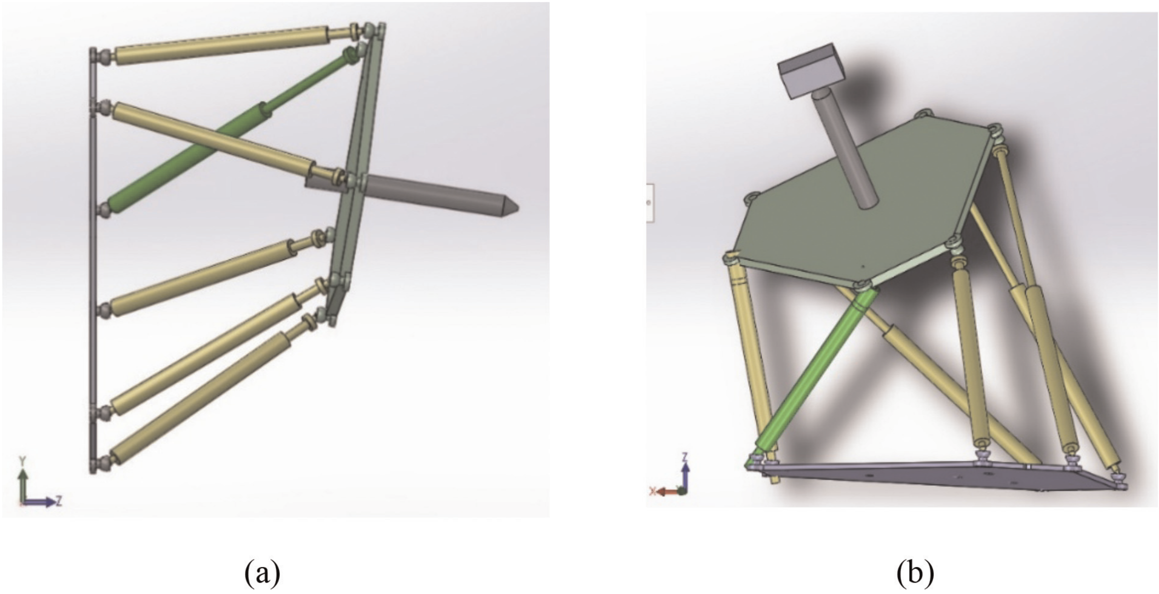
The determinant of the Jacobian matrix	$\det\left([J]^{-1}\right)$
Dexterity	$[DEX] = \left\lVert \det\left(J^{-1}\right) \right\rVert \bullet \lVert J \rVert$
Local conditional index	$LCI = \frac{\sigma_{\max}(J)}{\sigma_{\min}(J)}$
Manipulabiliy	$Manip = \sqrt{\det(J * tr(J))}$
Global conditional index	$\eta = \left(\int_{WS} k \bullet dW\right) / \left(\int_{WS} dW\right)$

Table 1.
Criteria for kinematic performances.



(a) (b)

Figure 10.
Assessment and optimization of kinematics. (a) assessment of configuration in real time (b) optimization using GA.



(a) (b)

Figure 11.
Assessment of kinematics using Solidworks. (a) forward kinematics (b) inverse kinematics.

location in a specific direction. However, the methodology requires knowledge of the Solidworks API script.

4.1.4 Durability assessment

Effective service life is determined by several factors, including:

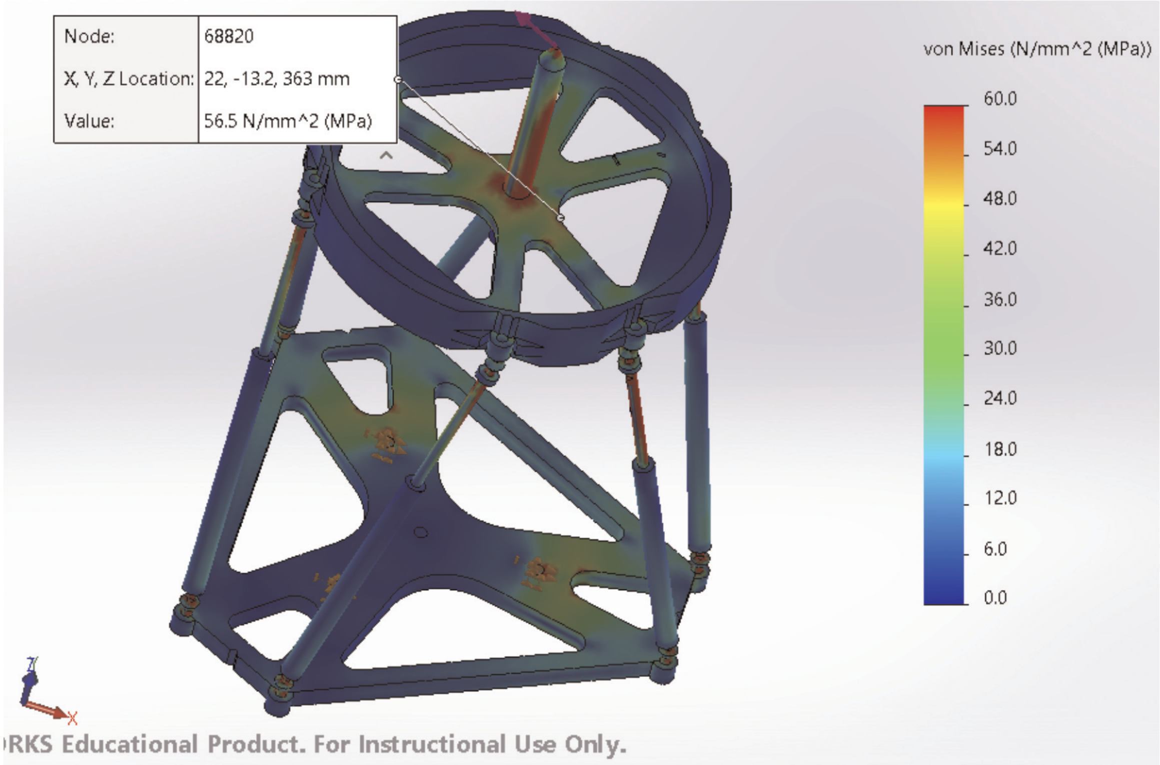
- load cycles;
- environmental factors: temperature, humidity, corrosion, etc.;
- selected materials;
- electromagnetic fields under which the system works.

Research results on evaluation of the effect certain expected loads on the service life of a product do have. A load cycle was considered. The stress level is VonMises stress extracted from 100 load cases at the same probe when the loads vary in different directions and amplitude. An example of VonMises stress level at probe for load case (no. 55) with 1000 N at tool is presented in **Figure 12**. The probe is located at platform because this part is the main for structural design optimization.

Material for platform is considered in this phase the polycarbonate plastic material. This material could be changed during further optimization steps.

The assessment of the endurance by effect of the stress state on the material took into account the Wohler curve of the polycarbonate plastic by applying the rainflow method. The results are shown in **Figures 13** and **14**. For the above load cycle the damage is 1.0434e-6 for a single stress sequence. This means that the life of the verified component is 958,405 cycles.

Rainflow algorithm is the most popular counting method used in fatigue and failure analysis for lifetime estimation of mechanical parts. The rainflow counting technique was introduced by Matsuishi and Endo in 1968 to extract closed loading



Node:	68820
X, Y, Z Location:	22, -13.2, 363 mm
Value:	56.5 N/mm^2 (MPa)

Figure 12.
Von Mises stress level at probe for load case (no. 55).

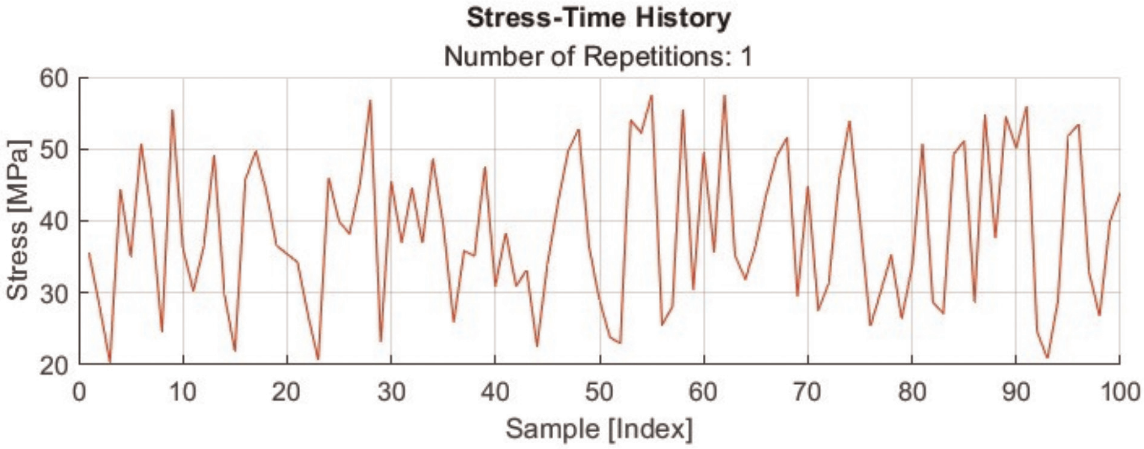


Figure 13.
Reference load cycle.

reversals or cycles for a correct estimation of fatigue. The "rainflow" was named in comparison to the flow of rain falling on a pagoda roof [23, 24]. For the studied example, the detailed rainflow diagram is presented in **Figure 15**.

Endurance evaluation can be done also using Solidworks software, but not with such detailed diagrams for post-processing and reports but with something else which is also important – durability in 3D fields.

4.1.5 Thermo-mechanical evaluation

Thermal flow can influence the performance of a robot. These aspects are even more important in the case of a surgical robot. The results of thermo-mechanical

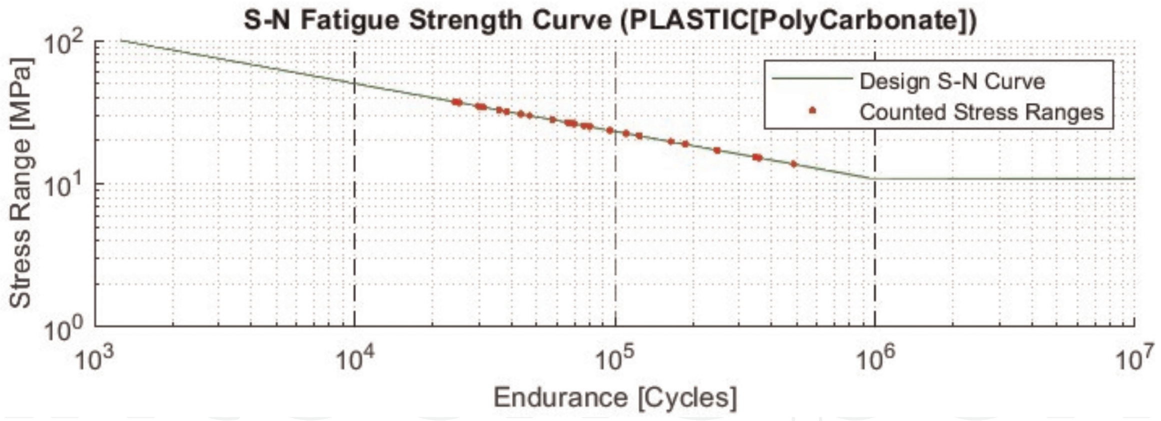


Figure 14.
Fatigue curve for plastic -polycarbonate.

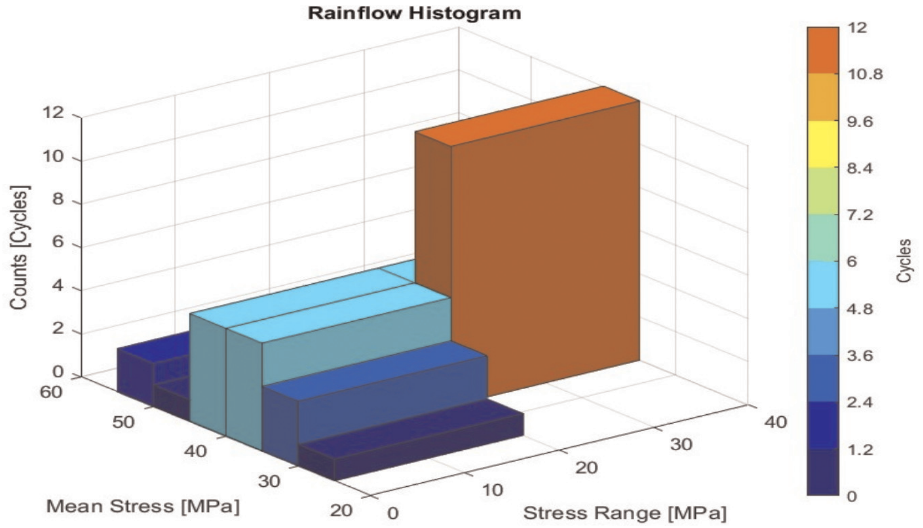


Figure 15.
Rainflow diagram.

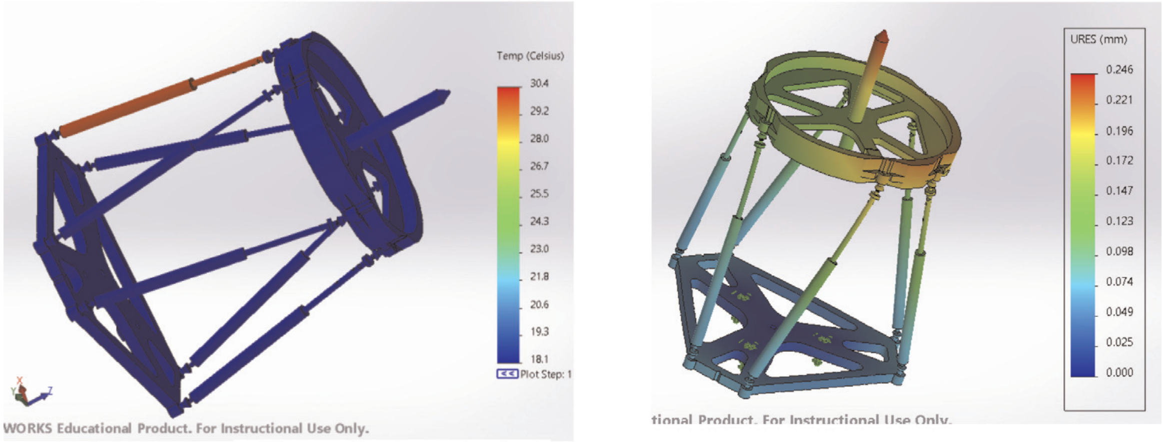
simulation for the surgical applications hexapod robot are further presented. Thermal load is considered overheating of an actuator from 18 to 30 degrees Celsius because of a failure at its motor. Because of to this thermal load, the total deviation at the end of the tool is 0.25 mm for presented model (see **Figure 16**).

In a surgical room, there could exist many thermal sources from the heating of electrical systems, heating flow, radiation, convection, advection, etc. An evaluation of thermal effects is mandatory for a surgical robot.

4.1.6 Damage detection

Structural Health Monitoring (SHM) is applied today to mechanical structures that require significant costs, for structures difficult to inspect or where human safety is a priority. The main task in this subject is damage detection. But damage detection involves today also methods to estimate damage location, damage size, or other additional information about the damaged area.

In this sub-chapter is presented an improved DLAC method for damage localization technique applied to a surgery robot structure. Basically, method use frequency



(a) (b)

Figure 16.
Thermo-mechanical analysis. (a) thermal field (b) thermal deformation.

shift for damage detection (Eq. (2)). The DLAC criterion was improved by transform equation into a probability index for a better assessment (Eq. (3)).

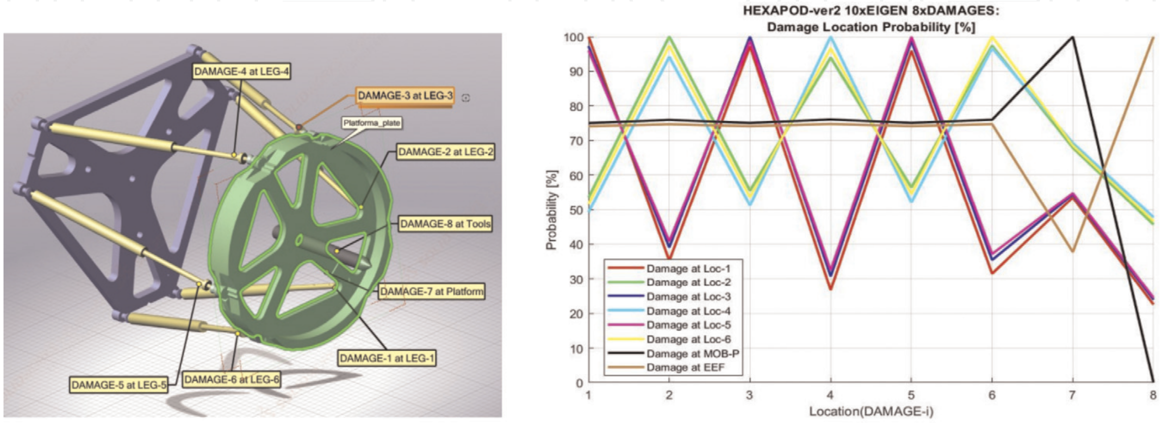
$$DLAC(i) = \frac{\left|\Delta\omega_E^T \Delta\omega_A(i)\right|^2}{\Delta\omega_E^T \Delta\omega_E\left(\Delta\omega_A^T(i)\Delta\omega_A(i)\right)} \tag{2}$$

where $\Delta\omega_X$ is the frequency shift for analytical or experimental (A, E) model.

$$probability(DLAC) = RESCALE(DLAC, 0, 100) \tag{3}$$

Successful damage localization technique depends on eigenmodes number. In **Figure 17** there are presented the set damages locations and final diagram for DLAC probability index.

The probability index of DLAC criterion shows the maximum value exactly where the damage was imposed in each model. This is possible when exist only one damaged area. In case of simultaneous existence of several damages, the DLAC method is no longer effective, being necessary to corroborate with other criteria for a correct evaluation.



(a) (b)

Figure 17.
Damage localization using 10 eigenmodes. (a) 8 damaged locations (b) DLAC probability index assessment.

Detailed examples for damage detection probability index can be found in [25].

The complete task of the simulations for surgical robot was developed based on MATLAB software [26], SOLIDWORKS Educational [27] and user defined programming routines, VB, API, etc., [28].

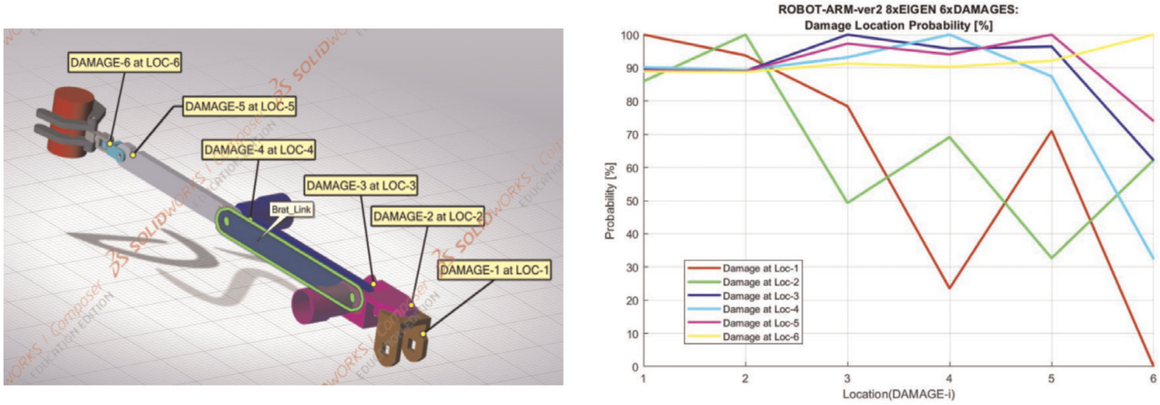
4.2 Damage detection for robotic arm

A similar damage localization technique was tested on the robotic arm of the visually impaired mechatronic system (see **Figure 2**. (a)). The simulation uses 8 eigenmodes and 6 damages.

One can conclude that simulation results prove the estimation for the damage location, as the higher probability of damages resulted for location no. 5 (see **Figure 18**).

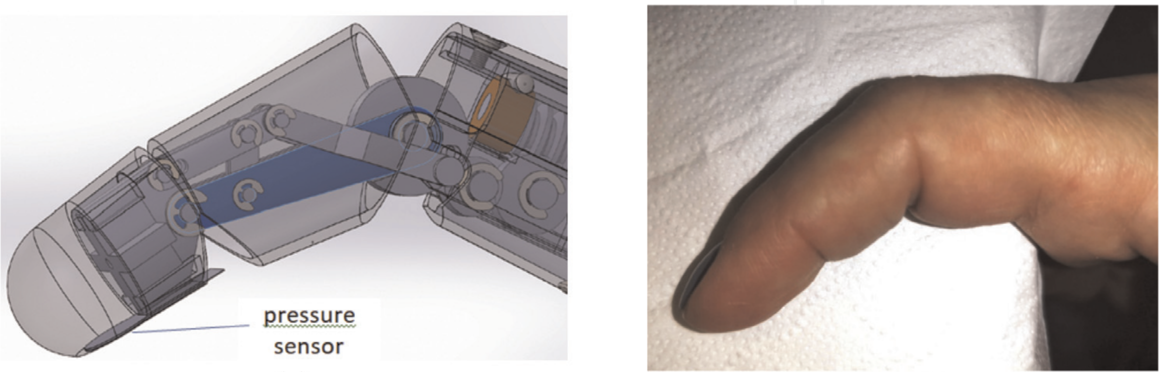
4.3 Optimization of geometric configuration for a hand prosthesis finger

The model of finger hand prosthesis has been built, as part of a research on biomechanical prosthesis (see **Figure 19**) and one important step prior to prototyping was that of optimization its geometry, specially its mechanical components (levers) dimensions.



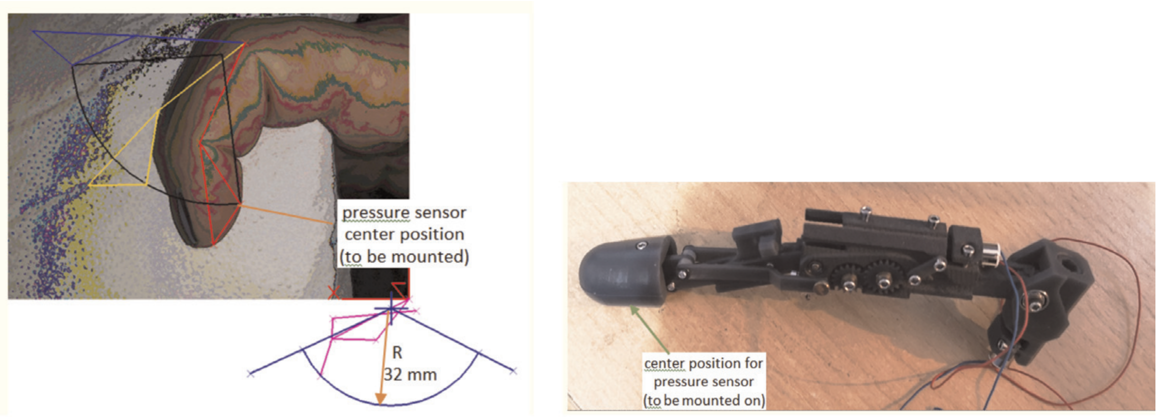
(a) (b)

Figure 18.
Damage localization using 8 eigenmodes. (a) serial robot - 6 damages (b) DLAC probability index.



(a) (b)

Figure 19.
Hand finger's motion. (a) finger model (b) real finger.



(a) (b)

Figure 20.
Hand finger components. (a) tip finger trajectory (b) finger prototype.

Basic finger's motion is that of rotation of phalanges so that to grab an object. Based on the 3D model, the fingertip trajectory was simulated (so that to be on a circle arc) and thus the position of the pressure sensor was determined (see **Figure 20**) at a radius of 32 mm. In the 3D model, the sensor is positioned at 28 mm. So, adjustments of levers' lengths have to be done.

5. Conclusion

Modern CAD design tools bring many benefits to their users. Solidworks is a design program with many features in mechanical design and not only for mechanical domain. Originally developed for the visualization and virtual construction of complex ensembles, the software has been developed in recent years into a complex assessment of overall tolerances, parts parameterization, kinematics, structural strength, the performance of the product, cost evaluation, etc. These benefits can be multiplied by using Solidworks API programming codes.

All stages from product design study to prototyping and/or manufacturingcan be solved with a single working tool, Solidworks software.

Technical conclusions:

1. Robot surgery design involves many aspects from medical, physics, engineering, prototyping and manufacture fields [29];

2. Damage localization is a reliable technique for monitoring of mechanical structures during evaluation, testing and service;

3. Programming tools increase performances in engineering design [30–33];

SolidWorks is the most advanced tool for engineers today because of its range of applications that can be involved in real product design and manufacture Solidworks is even more advanced. Solidworks API can build assemblies in a fully automatic fashion. An entire assembly can be obtained based on the parameterization of the components and commands in the API programming code. And the adventure to new levels of engineering design just starts. Multi-physics, multi-disciplinary and multi-platform in computer and engineers'ability will grow.

The result of the design with SolidWorks software will be analyzed cinematically and dynamically in order to verify and validate the concept and solution for the robot system engineered.

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Conflict of interest

The authors declare no conflict of interest.

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