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COMPUTER AIDED DESIGN OF UNCONVENTIONAL ROBOTIC DEVICES

Summary: The aid of 3D CAD/CAM/CAE systems represents very important power tool in process of the technical system design. Their utilisation enables an increasing of the high added value of solved construction tasks. But complex CA systems are not "self-solvable" systems and therefore the intellect and abilities of designers will remain on the first position.
Keywords: Biorobotic gripper, computer simulation, flexible elements, pneumatic artificial muscle, stranded wire.

INTRODUCTION

In the case of non-traditional kinematic structure of the robot, respectively application of unconventional types of actuators and transmission mechanisms in the construction of their subsystems, it is necessary to look for new 3D modelling techniques which would provide the creation of virtual models with the required parameters.

Examples of such non-traditional structures may be the construction of biorobotic gripper (BRG) which design is optimised in frame of the dissertation thesis solution in the Department of Automation and Production Systems at the University of Žilina.

BRG is the end effector applicable to industrial and service robots where this one substitutes the conventional handling robot effector by its properties. The basic characteristic of this gripper type is a versatility and flexibility of its use. Application of biorobotic grippers represents a highly innovative approach to the handling tasks executing in the implementation of specialized applications, either in industrial, service or special (e.g., undersea and space) environments.

DESIGN AND SOLUTION OF THE BRG VIRTUAL 3D MODEL VARIANTS

The initial draft version of the biorobotic gripper was modelled in the system CATIA V4. Whereas the work place of the Department of Automation and Production Systems has used the licensed program Pro/ENGINEER WF4

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(*CreoElements/Pro*) [3], it was necessary to ensure migration of data already generated. For this purpose, it was used the principles of the conversion and the export of virtual 3D model data into a neutral formats understandable for both CAD systems. Among several available formats such as STEP, IGES, STL, VRLM, Neutral, 3Dxlm has been turned out as the best IGES through its good readability for Pro/ENGINEER WF4 and maintaining the required elements of the original model (volume, area, coordinate system, the reference plane, axis, etc.). The disadvantage of this solution is failure to maintain the model tree and creating sequence of elements and their parameters of which the model consists (*extrude, cut, hole, round,* etc.). The model is exported just as elemental (solid) object without the possibility of its reverse editing.

Thus the primary variant of the biorobotic gripper was imported and assembled part by part into the assembly (Fig. 1a) [1]. Initial range of motion was detected on the base of utilisation of simplified computer simulation – by the discrete compilation of fingers and their positions in the border cells. Based on the visualization of this variant, the easier recognition of the spatial and functional relationships among different parts of the model were allowed. This made it possible to optimize (simplified) the structure of design with regard to the technology of its production ("Rapid Prototyping - Fused Deposition Modelling"), which led to the reduction in the number of assembly components. The result of these modifications was the second variant of the biorobotic gripper (Fig.1b) [1]. The modified components were manufactured for assembling of the prototype of one finger.

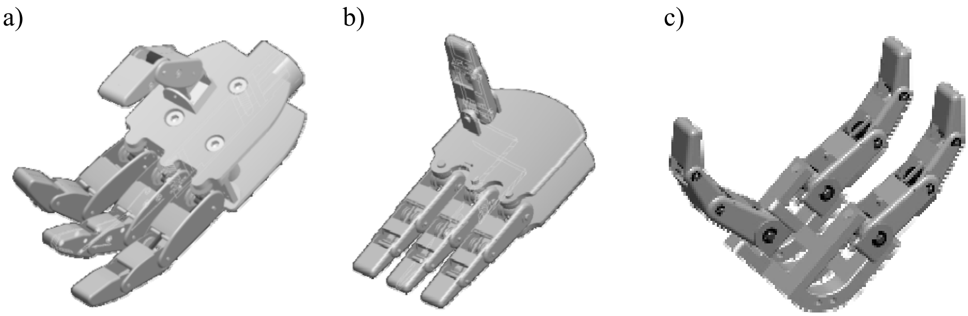

Fig. 1. Virtual 3D models of the biorobotic gripper:
a) the first variant, b) the second variant, c) the third variant

Kinematic limitations detected after functional analysis performed on the finger prototype showed the need of further modification and simplification of the biorobotic finger design. Modificative facilities in the environment of Pro/ENGINEER WF4 allow create new variant from previous model with keeping of initial structural and functional dependencies. Modification procedure consists of suppressing (*"Suppress")* of the parts which forming the palm and removing of the thumb subassembly from the superior hand assembly *"Model*

Tree". The new configuration of BRG is given by new placement of three fingers at the palm. Two fingers are placed in the same row and the third one is in the opposite row – at angle = 90°. This modification is possible to do in the active assembly through the *"Edit Definition"* of the palm new model via *"Component Create"*. This model is coupled through references to the connecting elements (shaft fingers). It ensures mutual associativity for the modification of mentioned elements in the direction *"Parents-Children"*. The internal section of the first phalanges was modified in analogous manner. The additional element of shaft was modelled after its length editing (Fig. 1c).

The subsystem of actuators for BRG consists of pneumatic artificial muscles (PAMs) which characteristics are currently most similar to the properties of human muscles. The PAMs are considered for the cables movement control. The cables are arranged in internal space of every finger and palm too and led out through hand wrist. PAMs will be placed in the forearm zone.

COMPUTER SIMULATION OF FLEXIBLE ELEMENTS

The basic problem of the described BRG mechanism simulation results from a large number of both degrees of freedom and members of the kinematic chain which movements must be controlled. The finger structure is an open mechanism with serially linkage chain for which the physical parameters and their boundary conditions are not precisely defined. Therefore, the principle of bionics and heuristic approach based on empiricism and analogy with human hands will be used for the motion simulation.

The first phase of the flexible components simulation is focused on computer modelling of artificial tendons (wires) as the flexible elements which constitute the actuation and transformation mechanism of the BRG propulsion subsystem. However, at the present time no known CAD/CAE systems support the possibility of modelling such flexible bodies directly. Therefore, the idea of implementing the necessary simulations is to use Pro/Engineer WF5 and to apply alternative approaches to modelling and simulation mentioned flexible (shape-flexible) elements.

The base stage is to focus an attention to the analysis of solutions of the mechanical system and defining of the problems too. The concept of a flexible element as was presented in the context of a body (e.g., steel stranded wire) is characteristic of its flexibility and/or elasticity. Flexibility means a change of shape in a plane parallel to the largest dimension of the body without altering its volume.

Aiming at the simulation problem of 3D flexible cable in equipment operation simulation platform, the cable model is classified as two types which are named as:

– model of constant length,

– model of changeable length.

Then two different simulation methods are put forward according to their respective 3D shape characteristics. Firstly, the catenary method is adopted to describe the model of constant length considering the gravity. The curve equation is deduced to be the final math model. Secondly, the model of changeable length is equal to draw a 3D line according two given 3D coordinate points and cylinder with certain radius around the line can be drawn with calling OpenGL API. The rendering effect of each model is presented to prove the simulation feasibility. Finally, the realization of mechanism called OpenGL call-back function combining with Vega is brought forward. It shows the greatest traits on the cable simulation in similar virtual reality system.

In this task we consider the cable as a 3D model with a constant length, resulting in the subsequent simulation procedures (chain method). Solution like this one represents the application of simulation based on object modelling features of the mechanism. The basic principle of testing is to simplify the real model to theoretical model, thus eliminating many parameters and variables entering into the process that affect the test results in ways previously unpredictable. Therefore, the BRG 3D model has been simplified to test the one. This is designed as a general mechanism of BRG subassembly containing only the elements directly coupled with the movement of the first wire. It means that the first phalanx is connected with the base through the shaft to the pulley by the motion constrain *"User Defined - Pin"* (defined as rotation around the axis).

Wire model is realized as a string created from the basic building element which is n-times inserted into the assembly and linked to the previous building element. Therefore, in the theoretical analysis we can conclude that if:

– n is number of elements of which the virtual 3D model of cable is composed, it can theoretically take values: $n\ (1, \infty)$,
– R is degree of similarity between both virtual and real models of wire expressed as a percentage of the fidelity model $R\ (0, 100)$ and it is expressed in relation to n as: $R = f\,(n)$ and
– dl is the length of the basic building element of wires and all elements have a constant length: $dl_1 = dl_2 = \ldots = dl_n$,

then l - total length of wire is expressed as: $$l = \sum_{i=1}^{n} dl_i$$

The basic building element of wire is modelled as a cylindrical body with given diameter which is closed from the one side by convex cylindrical surface and from the second side by concave surface. These both surfaces create references on the building elements for the mutual interconnection between every couple of elements in the chain. Fundamental element must include also coordinate planes and axes of cylindrical surfaces and coordinate points which are created at the intersection of the axes.

Trajectory of wire is defined by the cable outlet (output) at the base, a rotating guide roller surface and point of its mounting to the phalanges. This trajectory is created in the model as *"Sketch"* associative curve changing its shape depending on the position configuration of characteristic elements in their mutual movement.

Stranded wire is assembled as the virtual mechanism by using of motion constraint in *"Assemble"* module where each element of wire is connecting to the motion links *"Pin-Axis Alignment"* (alignment of axes of cylindrical surfaces) and *"Slot - Point on Line"* (alignment points and curve-trajectory) (Fig. 2). Characteristic of flexible bodies is their flexibility in a defined direction and a maximum value of bending. So these data are the boundary conditions for the simulation of their movement. Therefore, the angle of the axis rotation of two neighbouring elements in their link *"Rotation Axis"* is limited in the angle range +/- 70°. To connect wire to the motion assembly, the first element is linked through the pivot to the phalange rotationally.

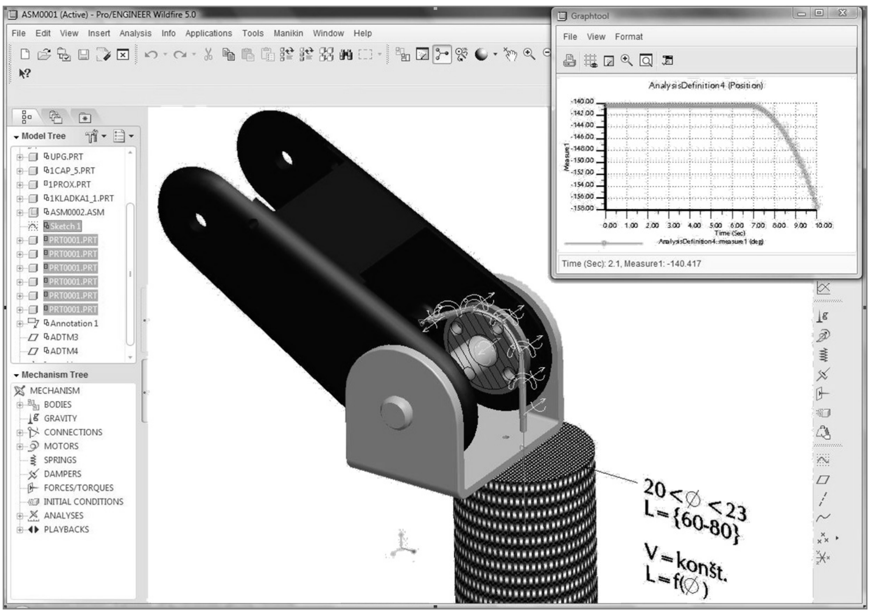

Fig. 2. Simulation of the mechanism 3D virtual model with flexible elements (wire, PAM)

In context with the simulation of pneumatic artificial muscle (PAM) we must know its characteristics. This information is described together with a mathematical equation in [2], where the dependency between length L and diameter $Ød$ of PAM is expressed. On the base of this mathematical relation the graphically simplified PUS parametric model is created in the form of a cylinder. The length and diameter of the cylinder are defined by the function *"Tools"* and

"Relations" as functions dependent on the control variable *P* which is determined and its value is changed by *"Tools" "Parameters"*.

The proposed simulation model is possible to test in two ways. The first way is in the application *"Mechanism"* where the motion mechanism is created by inserting the actuator *"Servomotor"* to axis of the shaft and by defining its parameters (e.g. *Profile-Velocity, Magnitude-Constant,* $A = \omega$). Through the function *"Mechanism Analysis"* we can create *"Analysis Definition"* which enables to show the behaviour of the simulated mechanism during its movement through *Playback, Graph* functions. Another way is to connect the second end of wire ("assemble" of the last element) with simulation model of PUS. The length of the PUS will be changed with subsequent change in control parameter *P* and by regeneration of the model. It causes the tension of cable and rotational movement of the phalange.

The results of the simulations are following:

– in proportion to increasing number of elements *n* the difficulty and time of simulation calculations are increasing. It could be caused by non-optimized calculation algorithm system for a given application and hardware performance PC.
– simulation based on variations of parameter *P* enables to obtain only discrete values (angular rotation, position of elements) which provide only a little information in comparison with the method of application *Mechanism*.

The output of the present solutions should lead to the identification of size and speed of shortening of individual stranded wires by realization of predefined movements. These data may represent the important input parameters for control of pneumatic artificial muscles.

DIRECTION OF THE BRG 3D MODEL FURTHER DEVELOPMENT AND TESTING

In the next phase of the biorobotic gripper design verification is planned a virtual testing of the BRG grasping ability. For this purpose the objects of simple shapes called “shape primitives” (e.g. prism, cylinder, cone and sphere) will be used. The main task will be to create the suitable methodology for determining of the contact points among BRG fingers and grasped object in CAE system environment. For this purpose the utilisation of function of program ProENGINEER - *"Collision detection"* - is considered.

CONCLUSION

A common problem in the phase of the BRG design is verification and reviewing of accuracy of the proposed variants of structures or modifications of the selected version in terms of its functionality. These testing of the BRG physical prototypes are time-consuming and expensive. The implementation of further design modifications is quite complicated.

Very progressive way is verification of the BRG design with application of both simulation and optimization methods are prepared as a computer program of CAE system on virtual the model. Using the simulation system allows to engineers to determine operationally how the various selected kinematic and geometric parameters affect the monitored links abilities of proposed mechanism - for example: grasping objects of different shapes. In that kind it's possible to evaluate the functionality of the proposed prototype before its physical implementation phase and thus avoid the time, material and financial losses for non-optimal variant.

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KOMPUTEROWE WSPIERANIE PROJEKTOWANIA NIEKONWENCJONALNYCH URZĄDZEŃ ZROBOTYZOWANYCH

Streszczenie
Wykorzystywanie systemów komputerowych CAD/CAM/CAE w znaczącym stopniu usprawnia proces projektowania urządzeń technicznych. Posługiwanie się nimi zwiększa wyraźnie wydajność pracy i pozwala na skuteczne rozwiązywanie występujących problemów konstrukcyjnych. Jednakże systemy wspierania prac inżynierskich nie są systemami samo-rozwiązującymi napotkane problemy, w związku z czym nadal na pierwszym miejscu niezbędny jest intelekt, wiedza i umiejętności korzystających z nich projektantów.
Słowa kluczowe: chwytak bioniczny, symulacja komputerowa, elementy elastyczne, pneumatyczny sztuczny mięsień, przewód.

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