# PROTOTYPE DEVELOPMENT OF A UNIQUE SERIAL KINEMATIC STRUCTURE OF MODULAR CONFIGURATION

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The authors are working closely the development of the prototype a unique serial kinematic structure of modular configuration. The prototype is developed in accordance with innovative ideas to develop a rotary linkage unlimited angle of rotation as the basic structural unit for such a kinematic motion structure. After verification of the prototype would be a proprietary idea of Universal Rotary Model (URM) to exercise in robotics as a basic building block movement of the robot or manipulator used mainly in industry eventually in the manufacturing technology utilizing unique and specific options suggested solutions. The article deals with the specifics of production documentation, available to select the optimum components, modifications and the effects of partial solutions, which together form a harmonious functional but extensible and modifiable whole.

**KEYWORDS**

*modular structure, construction design, serial kinematics, design optimization*

## 1 INTRODUCTION

The modular configuration of the construction of serial kinematic structure has an irreplaceable position. The module as a basic building block modular structure, structurally, functionally and structurally separate unit. Basically it is materialized on the implementation of the basic functions of the motion - the movement kinematic series, and in the case of homogeneous structure. The modular system is by definition [Svetlik 2012] coherent system of motion module (that is unified units, functional nodes, building blocks ...) in the logic (structural, systemic, concepts, kinematic, ...) arranged higher functional unit, fulfilling the required parameters and job functions. The module is in this sense seen as a rotational movement a key building block for the required structural building without limitation the degree of rotation. Simpler, more specifically, that is, the rotation is not limited to such. Max. 3 speed, thus 6π, but an infinite number of speeds, thus ∞π. On this subject, there are already a number of scientific publications, where you can learn more details and also a deeper understanding of the ideas and principles that particular area of research uses [Svetlik 2012a, Svetlik 2014].

A prerequisite to a deeper software analysis is the software knowledge of CAX systems. For optimization and development CAX systems constitute an irreplaceable role in the efficiency and effectiveness of the proposed solutions. [Korba 2014, Korba 2015, Dobransky 2016b].

## 2 MODULARITY OF THE TECHNICAL STRUCTURES

Development and production of modular production technology becomes harsh reality of the present and on the basis of conclusions of the expertise and perspective development of manufacturing technology. This fact is documented programs of technical innovation structures of manufacturers in this demanding and technically difficult access.

Modularity manufacturing technology is the real answer to the competitiveness of manufacturers of this technology on the world market, in response to the production efficiency of this technique while maintaining adequate market position, the answer to meet the economic needs of the general mechanical engineering through flexibility and elasticity responses producers of this production to market demand, respectively customers.

Characters of module:

- Autonomy (functional, Control, Driving, mechanical, energy), ie autonomy in the implementation of its functions to specified parameters.
- Integration (structural, functional), i.e. the spatial arrangement of all components and assemblies necessary for the functionality of the module into a single functionally and spatially coherent whole,
- Structural uniformity, i.e. uniformity of structure for the implementation of the same type of function (translational, rotational movement), the creation of the Council dimensional types (in our case we will deal with only partial rotational movement within the module)
- Compatibility, i.e. mechanical connection of the other module, respectively. Energy connection to the central distribution system of higher functional unit, respectively management interface to the central bus control gear - blocking system of higher functional unit.

The specific architecture of modular technical structure assembled from modules shall comply with the technical parameters of the requirements of applications satisfy the requirements of quality, durability and safety. The system has a modular technical architecture - independent modules are interchangeable connections with other parts of the modular technical architecture and it's implemented with the standard (resp. Purpose) connecting elements, so-called interfaces. Characters module and shape of the module depends on its functionality in a modular system and parameterization requirements resulting from it - characters, namely:

- Can be linked with adjacent modules
- Can rotate or change the position of adjacent modules.
- May be heterogeneous or homogeneous (in our case we are considering homogeneous)
- By type of relative position and coordination it can be applied to a parallel or serial structure of the technical system (while considering only the serial structure)
- The number of drives and the number of degrees of freedom determines its reach,
- Type of applied coupling mechanism (interface) determines the ability of its metamorphosis,
- Active autonomous module can be built most often on a rotation principle or linear movement (while we consider only the construction of rotary motion module)
- Passive autonomous module is used to achieve the desired parameters, no moving parts (task is to combine active modules).

In the design of modular structures it is appropriate to apply the principles of designing modular manufacturing techniques. Production devices are sophisticated mechatronic systems. If we consider many types of applications, we have to take into account their significant functional difference. Whether it is a new design or just an upgrade of existing types, there is always a need for cooperation of a wide range of experts from different fields such as: construction, technology, management, etc. In the current competitive environment, it is necessary to focus on the use of modern techniques, processes and information technologies that contribute to the quality of proposals and to shorten the time to solve them.

The general procedure for the formation of a technical system is sophisticated in detail for some time. For very rapid evolution of requirements and current status of the company, this model must be constantly improved. We must not forget the analysis of the consequences and measures relating to technical systems, methods and resources for their design and implementation [Sebo 2012, Bozek 2015].

## 3 URM 01, 02 – UNLIMITED ROTATION MODULE

Designed module with a "URM 01" (Unlimited Rotational Module type 01) is a rotary module with unlimited rotation, Figure 1. The URM 01 is designed for machines with the function of rotational movement without restriction. The concept and design is based on extensible - a modular principle. The main advantage of the proposed solution is the ability to compile a single module type machines with a variety of transport options and degrees of freedom of movement when using the option infinite rotation of two adjacent modules, which interconnects the rotary motion joints.

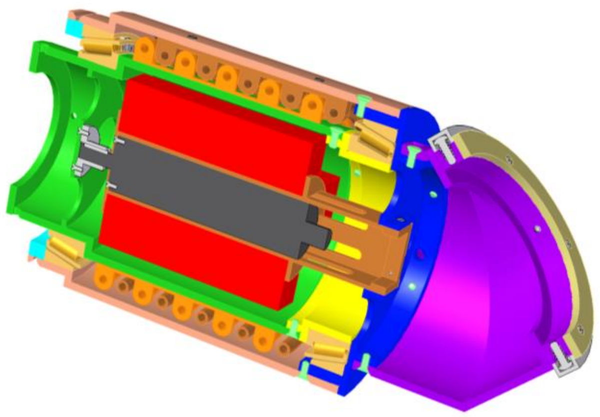

**Figure 1.** First virtual prototype of URM 01

Assembling modules URM into options of kinematic structure provides the widest range of the working space and the good attainable desired point in the workspace. On the other hand, also ensure the safety of operation by at any position of the kinematic chain can be self-collision of the kinematic structure. This condition may not necessarily be respected, because it is in stark contrast range from maximizing workspace and configurability. It is probable that the different degrees of freedom of movement should be selected not always identical to the angle of curvature of the URM 01 module. It is also likely that the particular application may be the angle of curvature of the appropriate module other than the one which is derived in virtual simulation conditions [Svetlik 2012b, Svetlik 2012c, Murcinkova 2013].

Due to guarantee autonomy and functional independence of URM 01 module is to have an independent power source and also an independent income stream data by the control system. Contactless energy transfer through the proposed induction for wireless and data transfer (control, correction and measurement data) to be transmitted from one wireless technology, for example Wi-Fi or Bluetooth. Utilization said construction of the proposed design of the rotary URM 01 module is expected in the construction of robots and handling devices, but after suitable treatment and in the construction of production machines with a special focus [Svetlik 2012a].

After the virtual simulation and virtual prototyping [Svetlik 2013] been launched production of a working prototype URM 02. The basic principle remained unchanged, but changes the external shape, Figure 4, 5. This change has been reflected from the surface aesthetics of purity technical work. Surface cleanliness is concerned mainly projections of circular cross-section of the original URM 01 module It also had to be taken into account the real availability of individual parts in accordance with an affordable price with respect to compliance with the requirements of rigidity, load carrying capacity and accuracy of the resulting physical structure. The result of the virtual model of URM 02 is shown in the sectional view of Figure 2.

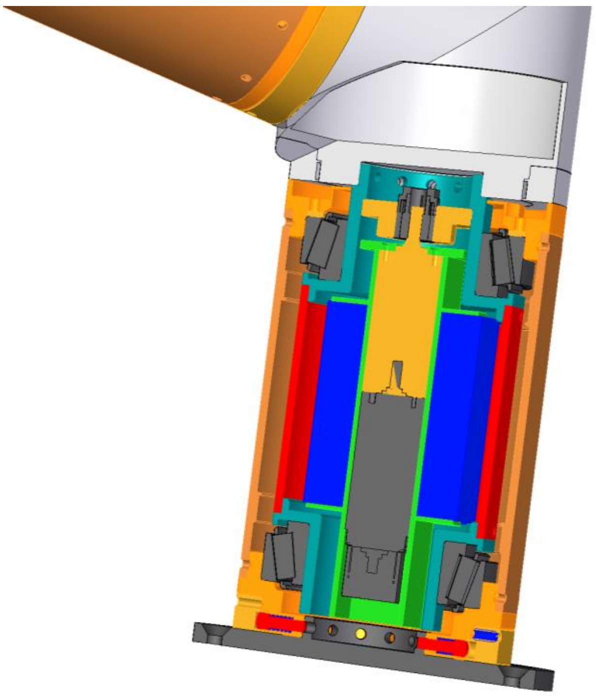

**Figure 2.** Second virtual prototype of URM 02

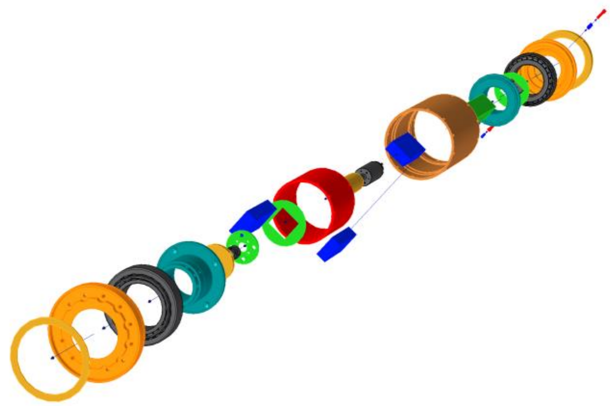

**Figure 3.** Mounting decomposition of URM 02

The basic motion module in a second design of the URM 02 takes account of the real availability of the required components on the market. Fitting decomposition of individual parts URM module 02 can be seen in Figure 3. The proposal sets of the real modules URM 02 is shown in Figure 4. The assembly is illustrated on Figure 5, is a patchwork of active homogeneous rotational motion module and passive modules curved at an angle of 75 °. The angle of curvature was chosen on the basis of empirical experience for authors and theoretical analysis of the projected attainment workspace.

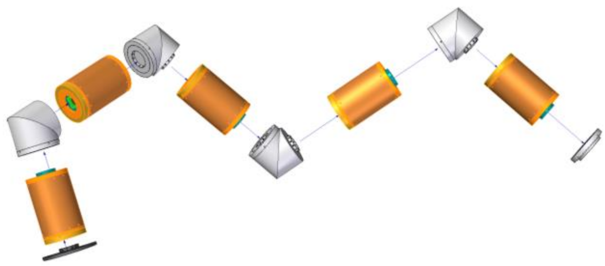

**Figure 4.** Mounting track physical structure assembled from URM 02

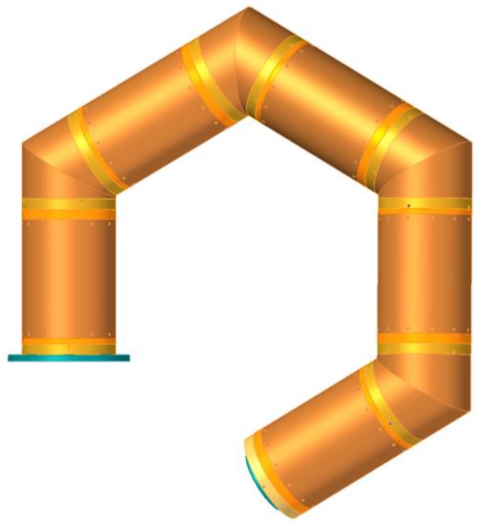

**Figure 5.** Assembled homogeneous physical structure of 5 DOF

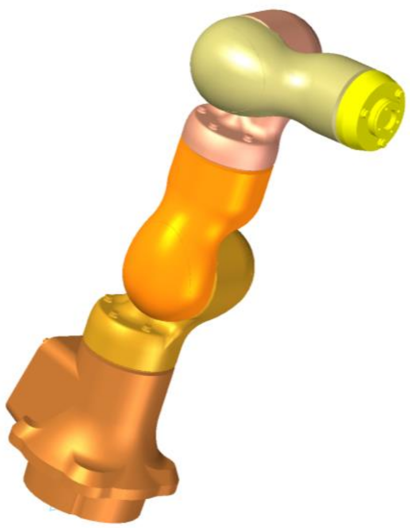

**Figure 6.** Competitive prototype physical structure of KUKA robot with a conventional arrangement

With an angle of 90 ° to the modular assembly principle represent prevalent configuration modules 90 to each other, as can be seen in Figure 6. The angle of curvature of the passive module 60° exist a possibility of self-collision. When designing the physical structure management with more DOF is therefore necessary to deal with this.

## 4 DIRECT KINEMATICS OF SERIAL HOMOGENEOUS STRUCTURE

There are several ways to investigate direct kinematics. However, the most common method for the investigation of the spatial mechanism is applied Denavit - Hartenberg principle (D-H). Often it used essentially characterized by a standardized method of deployment coordinate systems that are assigned to individual modules. [Svetlik 2012a] The main assumption is that any interconnected two coordinate systems can be described by four variables: $\vartheta_i$, $d_i$, $a_i$, $\alpha_i$. Reflecting a first angle of rotation, a pair of translational motion and the rotation angle of the last (maintaining the sequence).

Fundamental transformation matrix between two coordinate systems placed in the mechanisms of physical units has the form: (1).

$$A_{i-1}^{i} = \begin{bmatrix} \cos\vartheta_i & -\sin\vartheta_i\cos\alpha_i & \sin\vartheta_i\sin\alpha_i & a_i\cos\vartheta_i \\ \sin\vartheta_i & \cos\vartheta_i\cos\alpha_i & -\cos\vartheta_i\sin\alpha_i & a_i\sin\vartheta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

While the homogeneous transformation matrix $A_{i-1}$ shows the relationship between two neighbouring coordinate system $LCS_{i-1}$ and $LCS_i$. It does not happen that almost never changed all the variables contained in (1). On average, only one value changes, because generally the technique is used mostly kinematic pair of fifth grade, having only one DOF. In our particular case, the trinity of variables $d_i$, $a_i$, $\alpha_i$ has a constant value, table 1.

**Table 1.** D-H parameters of the selected mechanism with 3 DOF.

| i | $\vartheta_i$ | $d_i$ | $a_i$ | $\alpha_i$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | $q_1 \in \langle 0, 5\pi/12 \rangle$ | 224 | 0 | $\alpha_1=5\pi/12$ |
| 2 | $q_2 \in \langle 0, 5\pi/12 \rangle$ | 224 | 0 | $\alpha_2=5\pi/12$ |
| 3 | $q_3 \in \langle 0, 5\pi/12 \rangle$ | 224 | 0 | $\alpha_3=5\pi/12$ |
| 4 | $q_4 \in \langle 0, 5\pi/12 \rangle$ | 224 | 0 | $\alpha_4=5\pi/12$ |
| 5 | $q_5 \in \langle 0, 5\pi/12 \rangle$ | 224 | 0 | $\alpha_5=5\pi/12$ |

$$l_0=0, \quad (2)$$

$$l_{11}= l_{21} = l_{31} = l_{41} = l_{51} =224, \quad (3)$$

$$l_{12} = l_{22} = l_{32} = l_{42} = l_{52} =0. \quad (4)$$

The value of municipal variable $\vartheta_i$ may be in the interval $\langle 0, 5\pi/12 \rangle$. Curving outward building module $\alpha_i$ = 75°, the value $l_{i1}$ = 224mm and value $l_{i2}$ = 0mm (used dimensionally and functionally identical modules, so it is a homogeneous kinematic structure), Figure 5.

After modification and amendment of constant values for the kinematic pair solved mover has a total transformation matrix (1) between two neighbouring coordinate system $LCS_0$ and $LCS_1$ shape (2).

$$\mathbf{A}_1^0 = \begin{bmatrix} \cos\vartheta_1 & 0 & \sin\vartheta_{1i} & 0 \\ \sin\vartheta_1 & 0 & -\cos\vartheta_1 & 0 \\ 0 & 1 & 0 & 224 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

We continue tackling direct linkage, i.e. the number of coordinates of the last $LCS_5$ on the basic $LCS_b$. Thus the entire necessary transformation matrix $A_{i-1}$ multiplied by each other. Resulting transformation matrix $Tb_5$ is given by (6).

$$\mathbf{T}_b^5(\vartheta_1,\vartheta_2,\vartheta_3,\vartheta_4,\vartheta_5) = \mathbf{A}_b^0.\mathbf{A}_0^1(\vartheta_1).\mathbf{A}_1^2(\vartheta_2).\mathbf{A}_2^3(\vartheta_3).\mathbf{A}_3^4(\vartheta_4).\mathbf{A}_4^5(\vartheta_5) \quad (6)$$

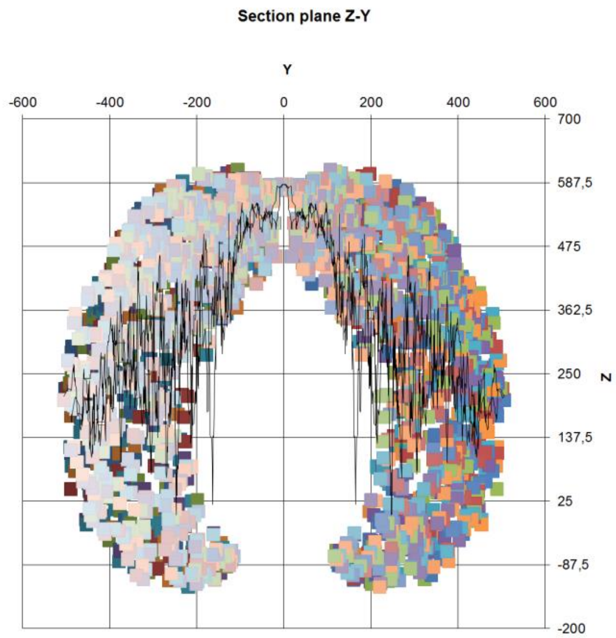


**Figure 7.** Cross-section of the workspace modular structure assembled from RM 02 to 5°DOF in the space Y-Z

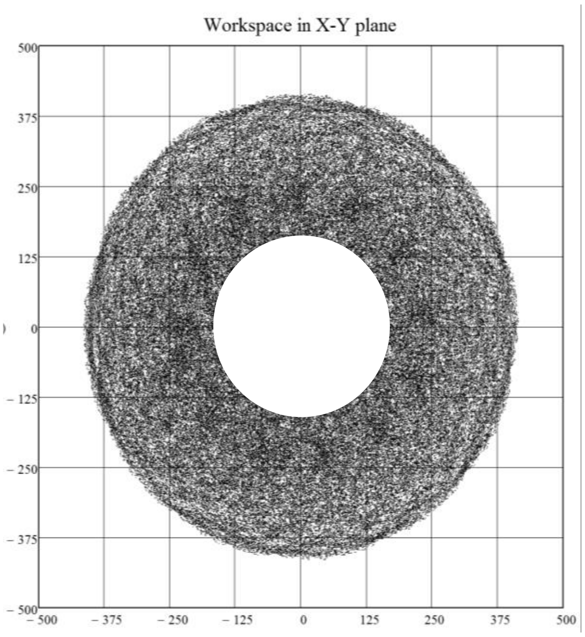


**Figure 8.** Cross-section of the workspace modular structure assembled from RM 02 to 5°DOF in the space X-Y

For the needs of numerical calculation and graphical display of the calculated values of point clouds workspace of the kinematic structure with 5° DOF was used Mathcad software. Variable movement of the variables in the matrix, in this case, the rotational angle $\vartheta_i$ of the rotation modules substitute be in the interval (0,2π) in increments of 0,09 rad.

The result of the simulation software is an indicative figure point clouds, which, after appropriate adjustments, we can display as the Figure 7 in the Z-Y plane, and the other view is X-Y illustrated on Figure 8

On Figure 9 depicts a confrontation with a variety of physical configurations, kinematics simulation results directly in the software Mathcad.

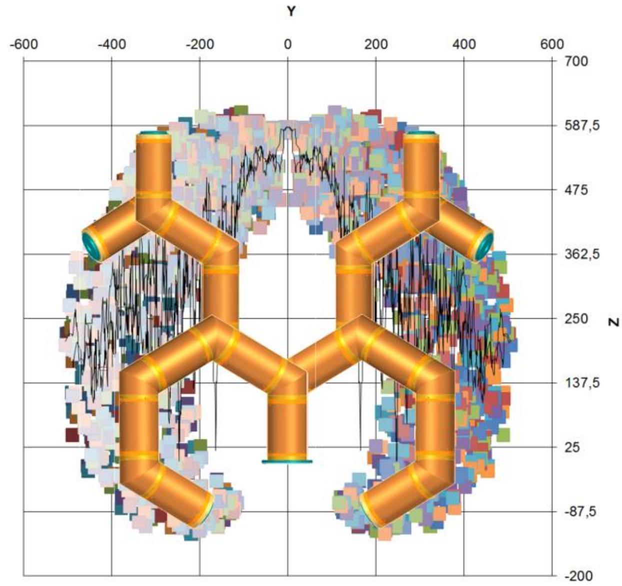


**Figure 9.** Hybrid display workspace modular structure assembled from RM 02 to 5DOF in the space Y-Z

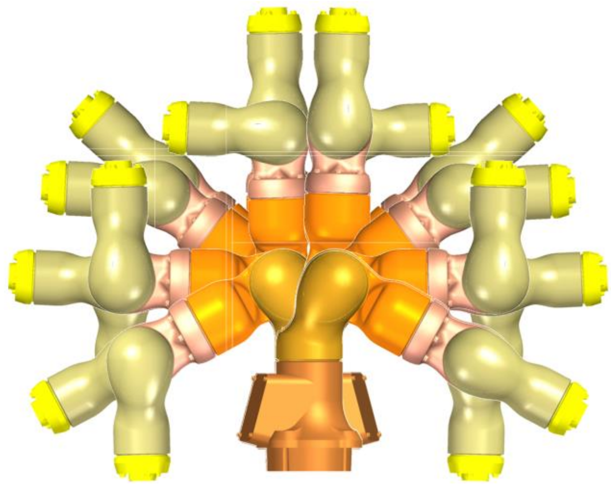

**Figure 10.** Kuka range workspace with 5DOF

Comparing outreach opportunities workspace standard solutions from KUKA, Figure 10 and proposed innovative solutions homogeneous kinematic structures are slightly in favour of the standard structure. But there is still room for further improvement and tuning issues examined [Krehel 2014, Krenicky 2014].

## 5 CONCLUSION

Generally speaking, the present prototype homogeneous serial kinematic structure on a modular basis parameter is approaching the established standard solutions. The authors plan to continue the development, testing and debugging prototype. In the future is expected to benefit to the fullest extent of modern production technologies with a potential solution involves problems in improving the parameters of the resulting structure. [Dobransky 2016a]

After summarizing the results of the work can be summarized as access to the construction of modular structures in the technology generally applicable principle with potential application in specific cases practice.

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