Autori:

Matijasevic,L.,Milivojevic,M.,Petrovic,P.

Naziv rada:

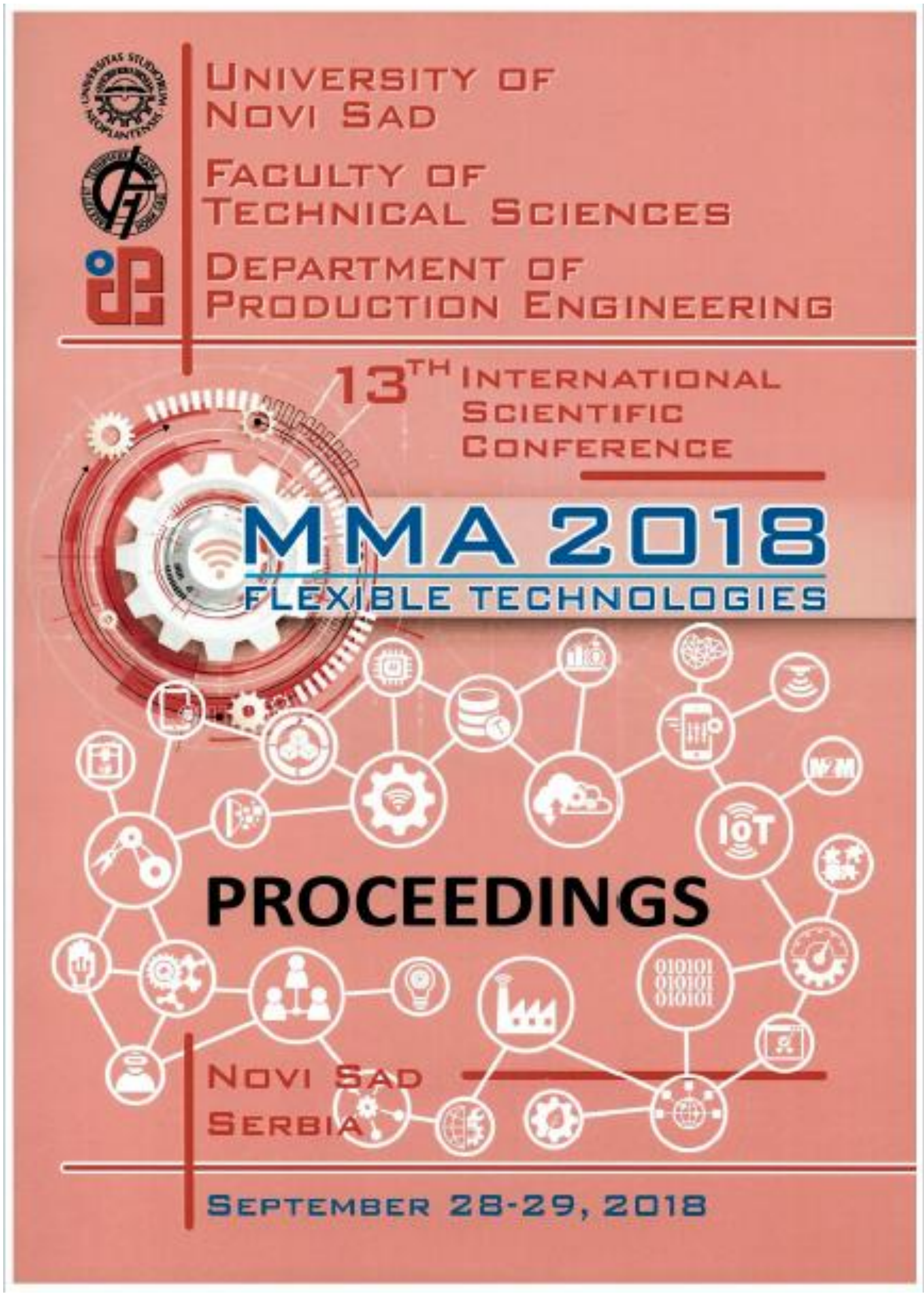
Multifingered under-actuated hands in robotic assembly

Konferencija:

13th International Scientific Conference MMA 2018 Flexible Technologies

Zbornik radova:

Proceedings, ISBN 978-86-6022-094-5, pp.91-94



UNIVERSITY OF
NOVI SAD

FACULTY OF
TECHNICAL SCIENCES

DEPARTMENT OF
PRODUCTION ENGINEERING

13TH INTERNATIONAL
SCIENTIFIC
CONFERENCE

MMA 2018
FLEXIBLE TECHNOLOGIES

PROCEEDINGS

NOVI SAD
SERBIA

SEPTEMBER 28-29, 2018

PROCEEDINGS OF THE 13th INTERNATIONAL SCIENTIFIC CONFERENCE

MMA 2018 - FLEXIBLE TECHNOLOGIES

Novi Sad, 2018

Publisher: **FACULTY OF TECHNICAL SCIENCES**
DEPARTMENT OF PRODUCTION ENGINEERING
21000 NOVI SAD, Trg Dositeja Obradovica 6
SERBIA

Organization of this Conference was approved by Educational-scientific Council of Faculty of Technical Sciences in Novi Sad

Editor: Dr Rade Doroslovački, professor, dean

Technical treatment and design: Dr Mijodrag Milošević, associate professor
Dr Dejan Lukić, associate professor
Dr Aco Antić, associate professor
M.Sc. Miloš Knežev, assistant

Manuscript submitted for publication: September 20, 2018
Printing: 1st
Circulation: 120 copies

CIP classification:

CIP - Каталогизација у публикацији
Библиотека Матице српске, Нови Сад

621.7/.9(082)
621.9(082)

INTERNATIONAL Scientific Conference MMA 2018 - Flexible Technologies (13 ; 2018 ; Novi Sad)
Proceedings / 13th International Scientific Conference MMA 2018 - Flexible Technologies, Novi Sad, 28-29 September, 2018 ; [editor Rade Doroslovački]. - 1st printing. - Novi Sad : Faculty of Technical Sciences, Department of Production Engineering, 2018 (Novi Sad : FTN, Graphics Centre GRID). VII, 428 str. : ilustr. ; 30 cm

Tiraž 120. - Bibliografija uz svako rad. - Registar.

ISBN 978-86-6022-094-5

a) Производно машинство - Зборници. b) Метали - Обрада - Зборници
COBISS.SR-ID 325441799

Printing by: FTN, Graphic Centre
GRID, Novi Sad

Financing of the Proceedings was sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia and supported by the Provincial Secretariat for Higher Education and Scientific Research of AP Vojvodina.

Section **B:** MACHINE TOOLS AND AUTOMATIC FLEXIBLE SYSTEMS, CAx AND CIM PROCEDURES AND SYSTEMS

MMA 2018
FLEXIBLE TECHNOLOGIES

13th INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, SEPTEMBER 28-29, 2018

Matijasevic, L., Milivojevic, M., Petrovic, P.

MULTIFINGERED UNDER-ACTUATED HANDS IN ROBOTIC ASSEMBLY

Abstract: *New production paradigm of mass customization imposes the development of flexible gripping systems with exceptional dexterity, capable of mimicking grasping behavior of human hands. In this context, the most demanding technical challenges are: motoric capabilities and related design aspects, overall weight and size, and tactile and other perceptual capabilities. Also, to make the gripper industry acceptable, it should be in affordable price range. Having all that in mind, concept of the multifingered under-actuated hand appears as good candidate to be an optimal, general purpose solution. This paper presents the general conceptual framework for development of multifingered hands which are based on under-actuation principle.*

Key words:-*Robotic assembly, Grasping, Multifingered hands.*

1. INTRODUCTION

Modern industrial robotic arms and hands excel over human's in most aspects. They are capable of lifting heavier loads, they are more repeatable and on top of that they are faster. With that said when it comes to gripping objects the situation is different.

Grippers used at assembly and manufacturing lines are typically simple mechanisms and are used for griping and manipulation of fairly simple parts and part families. New production paradigm of mass customization requires flexible gripers that are capable of in hand manipulation for task of manipulating complex object of different sizes and shapes.

This paper there will focus on robot grasping foundations and on human and robot dexterous manipulation. Paper concludes with multifingered under-actuated hands for dexterous and cognitive grasping and manipulation of objects in industrial setting.

2. ROBOTIC GRASPING FOUNDATIONS

End-effectors on a robot arm, that is used to grasp and manipulate object is a gripper. Based on their morphology they are separated into two main groups, regular grippers and robotic hands, as shown on Fig. 1.

Dexterity or, as described in [3], easy in-hand manipulation of object, after it was grasped, is main difference between these two groups. Grippers are fairly simple mechanisms that work on simple principles and can't perform in hand manipulation. Example of those grippers range from magnetic and pneumatic grippers or three finger adaptive grippers. Robotic hands are divided into three groups. There are under-actuated hands (where number of DOF of finger, n, is larger than number of actuators, m), fully-actuated hands (n=m) and humanoid hands. Humanoid hands are made to, more or less, recreate human hand's grasping capabilities and morphology. In industrial setting, however, usage of humanoid hands is scarce. Reason for that is found in robustness and overall cost of used grippers. Functionality of regular grippers satisfies needs of industry because of their simpler mechanisms that makes them robust and they cost less than multifingered humanoid hands. On the other hand they are less flexible than robotic hands and mass customization imposes flexibility as main ability that gripping systems must have. Robotic hands can perform in hand manipulation regardless of shape of object they manipulate. Three and more fingers grippers are flexible enough to manipulate objects of different sizes and weights and also different stiffness.

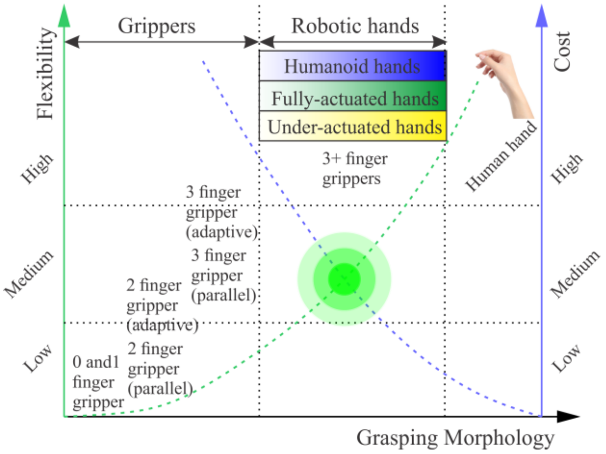


Fig. 1 Classification of gripers, from zero finger grippers (e.g. magnet gripper) to a human hand, based on their morphology, flexibility and overall cost.

So to make optimal solution, from mechanical standpoint, compromise of cost and flexibility must be found, and that area is illustrated in Fig. 1, with green circles. Another aspect of robotic hand systems is cognitive aspect. Just like with humans, grasping system needs to be able to define optimal solution for grasping different objects and by implementing this aspect robotic system becomes more flexible.

Notice that robotic grasping occupies multidimensional space that spans from mechanical over control complexity to cognition, so Fig. 1. does not illustrate that whole space.

2.1 Grasping theory

Determining conditions for grasping and manipulation of certain object requires fundamental definitions to be described first. There are several definitions in grasping, [2].

Definition 1: A grasp is commonly defined as a set of contacts on the surface of the object, which purpose is to constrain the potential movements of the object in the event of external disturbances. To be able to determine forces and torques that are required for manipulator to exert on the contact area a proper contact model should be defined. There are two main approaches in robotic grasping: analysis and synthesis.

Definition 2: Grasp analysis consists on finding whether the grasp is stable using common closure properties, given an object and a set of contacts. Then, quality measures can be evaluated in order to enable the robot to select the best grasp to execute.

Definition 3: Grasp synthesis is the problem of finding a suitable set of contacts given an object and some constraints on the allowable contacts.

A contact can be defined as a joint between the finger and the object. The shape of the contacting surface and the stiffness and frictional characteristics of the contacting bodies define the nature of this joint. Contact models maps the forces that can be transmitted through the contact on object. There are three contact models: point contact without friction, point contact with friction and soft finger contact model.

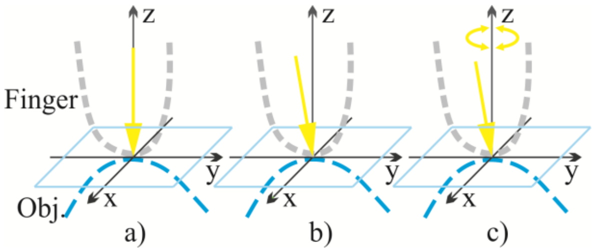


Fig. 2 Contact types: a) point contact without friction, b) point contact with friction and c) soft finger contact.

Point contact without friction, shown in Fig. 2 a), can only transmit forces along the normal to the object surface at the contact point. It does not represent the real contact that appear in robotic manufacturing operations. Point contact with friction, shown in Fig. 2 b), is used when there is significant contact friction, but the contact patch is so small so that no usable friction moment exists. It can transmit forces in the normal and tangential directions to the surface at the contact point but can't transmit moment components. Soft finger contact model, shown in Fig. 2 c), is used when the surface friction and the contact patch are large enough to generate significant friction forces and a friction moment about the contact normal. This model also correlates to usage of palm in grasping. In human case, palm is used extensively in grasping tasks, so in robot gasping it needs to be taken into account.

When discussing the ability of gripper to constrain movement of manipulated object, there are two closure properties that describes stable grasp of an object. Those are form and force closure.

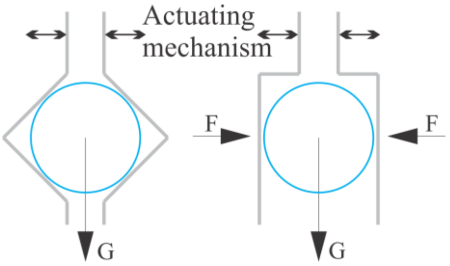


Fig. 3 Form and force closure interpretation

A grasp is in form closure, if the location of the contact points on the object ensures its immobility and grasp is in force closure, if the fingers can apply, through the set of contacts, enough force and torque on the object, which means that any motion of the object is resisted by the contact forces. Form closure is a stronger condition. Force closure is used when performing precision grasping, but it requires control of internal forces, [2].

Besides achieving proper closure property, for hand to be dexterous it requires grasp synthesis to provide suitable hand configuration for grasping, which is explained in [2].

3. DEXTEROUS MANIPULATION

The concept of dexterous manipulation is most important aspect in making of more flexible griping systems (mechanical hands, both robotic and prosthetic) that can mimic functionality of the human hand. To be able to accurately define dexterity it is important to consider decomposing manipulative tasks first. Manipulative tasks can be observed from object or environment-centric and hand-centric point of view, [3]. Consider opening a bottle of water. Object-centric view of the task would be: there needs to be rotational movement about axis of cap of bottle and axial movement along that axis to remove the cap. When considering hand-centric views this can be done multiple ways. It can be done within hand motions of thumb and forefinger or for example with power grasp of the cap and motion of entire arm to do the same job. There are multiple options to choose from when considering hand-centric point of view, and due to so many possible ways to do the task, object-centric view of manipulation task does not directly correlate with hand ability. So, given the circumstances, artificial grasping system should be able to distinguish different object properties and compute optimal approach to the given task. And mechanically, artificial hand needs to be dexterous enough to be able to perform computed grasping of an object.

Dexterity, in broad meaning, can be described as skill to use hands, [1]. It is often referred to as in-hand manipulation. So, the most dexterous hand, would be the one that could serve as a general-purpose manipulator, capable of performing the most diverse set of operations in a manufacturing environment. This definition would be valid if dexterity would come only from mechanical capabilities of hand mechanisms. When we take human grasping capabilities in consideration, dexterity could be defined as task of finding optimal kinematical solution for any situation and in any condition. This definition focuses not only on mechanical capabilities of hand to allow the versatility of dexterous movements, but on motor control systems to adapt movements to challenging environmental conditions.

Dexterity of human grasping is highly dependable on synergy of torso, arms and hands [4]. Most tasks of grasping are performed not only with hands but with arms and torso also. This ability is crucial to implement in artificial grasping system. In bimanual assembly systems, for instance, using multifingered hands on both arms of robotic assembly station leads to optimal assembly of objects where one hand can be used as fixture and other as tool used for assembly. This ability is essential when task is manipulation of larger objects, but when it comes to precision work, in-hand manipulation is crucial. When observing human grasping, for instance in precision soldering, we tend to decouple some joints by, for example, resting elbow joint or forearm on the working table. This makes that precision task dependable solely on in-hand manipulation.

So, with all mentioned in above sections, concept of the multifingered under-actuated hand appears as good candidate to be an optimal, general purpose solution for solving both mechanical and control part of complex tasks of grasping.

4. MULTIFINGERED UNDERACTUATED HAND

Complexity of the control and complexity of mechanisms incorporated in multifingered hands dictates actuation systems that are expensive, heavy, and hard to put in one, decent size, user friendly package. Because of these disadvantages, efforts are made in order to develop under-actuated fingers for multifingered hands.

4.1 Under-actuated robotic hands

Under-actuated robotic hands have become quite popular in industry and research applications, for a number of reasons. Hands such as these occupy a niche among the wide spectrum of robotic hands that lie between simple 2-fingered industrial grippers and complex 5-fingered anthropomorphic hands. Utilizing usually one actuator or less to operate a single finger, these hands allow a much more simplified control compared to traditional fully actuated multi-finger hands. Low cost, simple design, and the potential for mass application all make under-actuating hands quite promising for current and future development in artificial prosthetics and humanoid robotics, [5]. The concept of underactuation in robotic fingers, with fewer actuators than degrees of freedom through the use of springs and mechanical limits, allows the hand to adjust itself to an irregularly shaped object without complex control strategy and numerous sensors.

Process of grasping, when closing on an object, can be divided into three essential stages: the initial stage, the pre-shaping stage, and the closing stage as described in [6]. In the initial stage, shown in Fig. 4. (a), the finger is straightened and only first segment is touching the object. The pre-shaping stage can be described as the interval beginning when actuation is applied and ending when any segment touches the object. During this time, the finger acquires a pre-shaped configuration. As shown in Fig. 4. (b), once the actuator moves down and applies a tensile force on the tendon, the finger will start closing. All the joints will be rotating simultaneously in a coupled relationship.

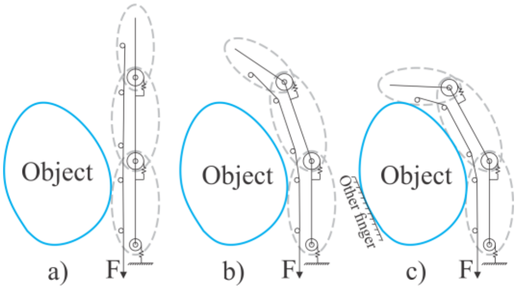


Fig. 4. Under-actuated finger with (a) initial stage, following (b) pre-shaping stage and (c) closing stage.

The closing stage will describe the interval beginning with the moment of object contact and ending when no segment can continue to move (when the grasp is completed). As shown in Fig. 4. (c), when the middle segment is blocked and the tendon is continuously pulled down, the distal segment can continue to bend because the two joint angles have been decoupled by the object. That is main advantage of under-actuated hands over fully actuated hands.

Two most popular and widely used concepts for under-actuated mutlifingered robot hands are tendon and linkage based mechanisms, [7], shown in Fig.5.

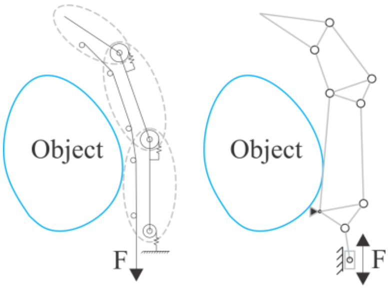


Fig. 5. Types of mechanisms, tendon and linkage based, used in under-actuated multifingered hands.

Pulley-Tendon/Cable driving of the under-actuated mechanical structures enables relatively simple and very compact designs, as well as remote location of the actuators. As described in [7] control of motion is problematic. Rigid linkage drive is more predictable, more accurate and more controllable. Rigid linkage drive is more appropriate for industrial use, and because this paper focuses on industrial application of these grippers, rigid linkage drive configurations will be used in following examples.

When observing their ability to grasp, known and unknown objects, it is important to state that stability of such grasp isn’t always same. Grasping with under-actuated multifingered hands can lead to two possible outcomes, stable or unstable grasp. As mentioned in section 2, form grasp is usually more stable than force grasp because in form grasping fingers are enveloping object contact points. Examples of the discrete states of stable grasp performed by the three phalanx finger driven by the two four bars mechanism (the object to be grasped is assumed fixed in space) is shown in Fig. 6.

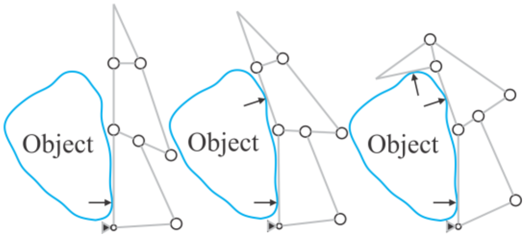


Fig. 6. Stable grasp of object.

In some configurations, the force distribution in an under-actuated finger can degenerate. The finger can no longer apply forces on the object, leading to, in some cases, the ejection of the latter from the hand, despite a continuous closing motion from the actuator. Discrete states of unstable grasp which is generated from initially stable grasp due to appearance of negative contact forces on some phalanx are shown on Fig. 7.

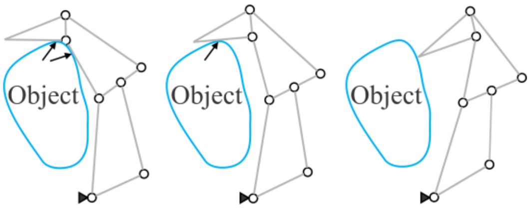


Fig. 7. Unstable grasp of object.

4.2 Multifingered human-like robot hands

Capabilities of dexterous grasping, mentioned in above sections, are easily achievable by human hand. So, it is only natural that many researchers are looking at human hands for inspiration. Human hand complexity makes it really hard to achieve anthropomorphic robotic hand that can do all the tasks human hand can. In the same time, being robust and sensitive, gives human hand abilities to do tasks in virtually any environment and the ability to do precise and some not so precise tasks like heavy lifting and similar tasks.

Multifingered flexible anthropomorphic grippers are rarely used in industrial setting. As mentioned, they are still in research stage and are primarily used in space exploration, military application and similar. One used in industry is shown on Fig. 8.

Fig. 8 The Robotiq 3-Finger adaptive gripper that’s used in industry.

Grasping of an object does not rely exclusively on mechanical capabilities of hand but on sensing and cognitive aspects also. Sensing technologies have improved over the years, so equipping fingers of robot hands with it, allows better force control and better motor control of grasping system. By implementing tactile sensors on fingers and give fingers the ability of object gaiting as described in [8]. System can use of tactile information from fingers and make proper grasp plan to grab an object.

5. FUTURE WORK AND CONCLUSION

There are several interesting topics which will be considered in future research. Kinematic properties of under-actuated finger will be studied in order to develop stable grasping system from kinematics standpoint. A proper grasp planning algorithm should be developed using 3D vision based systems working in conjunction with tactile sensors that can give information about grasping quality as well as object properties. Finally development of under-actuated multifingered hand system for use in industrial setting for small-batch assembly is a ultimate goal of this research.

6. REFERENCES

[1] Sturges, H.: *A Quantification of Machine Dexterity Applied to an Assembly Task*, Int'l J. Robotic Research, vol. 9, pp. 49-62, June 1990.
[2] Beatriz, L., et al.: *From Robot to Human Grasping Simulation*, Springer, London, 2014.
[3] Bullock, M., Ma, R., Dollar, A.: *A Hand-Centric Classification of Human and Robot Dexterous Manipulation*, IEEE Transactions on Haptics, vol. 6, pp. 129-144, April-June 2013.
[4] Pettinato, J., Stephanou, H.: *Manipulability and Stability of a Tentacle Based Robot Manipulator*, Int'l Conf. Robotics and Automation, pp. 458-463, USA, IEEE, Scottsdale, May 1989.
[5] Liarokapis, M., Dollar, A.: *Deriving dexterous, in-hand manipulation primitives for adaptive robot hands*, Intelligent Robots and Systems, pp. 25-27, Canada, *IEEE*, Vancouver, 24-28 September 2017.
[6] Long, W., et al.: *A highly-under-actuated robotic hand with force and joint angle sensors*, Intelligent Robots and Systems, pp. 25-27, California, *IEEE*, San Francisko, 25-30 September 2011.
[7] Birglen, L., et al.: *Under-actuated Robotic Hands*, Springer, Berlin, 2008.
[8] Ma, R., Dollar, A.: *An under-actuated hand for efficient finger-gaiting-based dexterous manipulation*, Robotics and Biomimetics, pp. 2214-2219, Indonesia, *IEEE*, Bali, 05-10 December 2014.

Authors: **Lazar Matijasevic, Milos Milivojevic, Full Prof. Petar B. Petrovic,** University of Belgrade, Faculty of Mechanical Engineering, Department of Production Engineering, Cyber-Manufacturing Systems Laboratory
E-mail: pbpetrovic@mas.bg.ac.rs;
lmatijasevic@mas.bg.ac.rs;
mmilivojevic@mas.bg.ac.rs;