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BACKSTEPPING CONTROL FOR HEXA-ROTOR MICROCOPTER

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Abstract: *Unmanned autonomous aerial vehicles have become a real center of interest. In the last few years, their utilization has significantly increased. During the last decade many research papers have been published on the topic of modeling and control strategies of autonomous multirotors. Today, they are used for multiple tasks such as navigation and transportation. This paper presents the development of a dynamic modeling and control algorithm - backstepping controller of an autonomous hexa-rotor microcopter. The autonomous hexa-rotor microcopter is an under-actuated and dynamically unstable nonlinear system. The model that represents the dynamic behavior of the hexa-rotor microcopter is complex. Unmanned autonomous aerial vehicles applications are commonly associated with exploration, inspection or surveillance tasks.*
Keywords: *dynamic model, dynamic behavior, unmanned autonomous aerial vehicles, autonomous hexa-rotor microcopter, under – actuated, dynamically unstable nonlinear system, complex, control strategies, backstepping controller*

INTRODUCTION

Unmanned autonomous aerial vehicles have become a real center of interest [1-14]. In the last few years, their utilization has significantly increased. Today, they are used for civil and military applications, for multiple tasks such as navigation and transportation. Unmanned autonomous aerial vehicles applications are commonly associated with exploration, inspection or surveillance tasks.

During the last decade many research papers have been published on the topic of modeling and control strategies of autonomous multirotors [15-30]. One of the unmanned autonomous aerial vehicles with a strong potential is the hexa-rotor microcopter.

The autonomous hexa-rotor microcopter have numerous advantages over quadrotors, since they can offer more:

- *power and*
- *speed, due to the properly position of the rotors.*

Figure 1. Hexa-rotor microcopter used for the experiments

The autonomous hexa-rotor microcopter , Figure 1, consists of six rotors attached to a rigid body frame and these additional two rotors make it able to carry:

- *more payload,*
- *the longest flight time and*
- *high maneuverability*

compared to quadrotor. The autonomous hexa-rotor microcopters have additional redundancy over autonomous quad-rotor microcopters.

The control design carried out for an autonomous quad-rotor microcopter can be applied to the autonomous hexa-rotor microcopter since they are modeled as a rotating rigid body dynamic system wih six degres of freedom (6 DOF), Figure 2.

Figure 2. The Hexa-rotor microcopter in hovering conditions

The autonomous hexa-rotor microcopter is an:

- *under-actuated and*
- *dynamically unstable nonlinear system.*

The model that represents the dynamic behavior of the hexa-rotor microcopter is nonlinear and complex. This paper presents the development of a dynamic modeling and control algorithm of an autonomous hexa-rotor microcopter.

The paper is organized as follows: Section 1: Introduction. In Section 2, the dynamic modeling of a hexa-rotor microcopter is presented. In

Section 3 backstepping controller for hexa-rotor microcopter is presented. Conclusions are given in Section 4.

DYNAMIC MODELING OF HEXA-ROTOR MICROCOPTER

The model [31-46] of the hexa-rotor helicopter and the rotational directions of the propellers are presented in Figure 3. This cross structure is quite thin and light, however it shows robustness by linking mechanically the motors. Hexa-rotor microcopter body is rigid. The six rotors are symmetrically distributed around the center. All the propellers axes of rotation are fixed and parallel. Propellers are rigid. These considerations point out that the structure is quite rigid and the only things that can vary are the propeller speeds.

The hexa-rotor microcopter configuration has six rotors which generate the propeller forces F_i $(i = 1,2,3,4,5,6)$ as it is shown in Figure 3. Control of quadrotor is achieved [2] by commanding different speeds to different propellers, which in turn produces differential aerodynamic forces and moments. In order to increase the altitude of the aircraft it is necessary to increase the rotor speeds altogether with the same quantity.

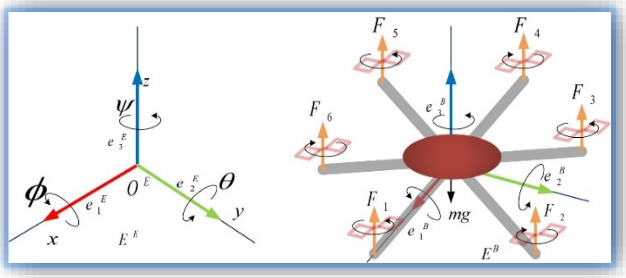

Figure 3. Hexa-rotor microcopter - a non-linear dynamic system

Each rotor consists of a:

- brushless DC motor and a
- fixed-pitch propeller.

This rotorcraft is constituted by:

- three rotors which rotate clockwise (1,3,5), and
- three rotating counterclockwise (2,4,6).

Forward motion is accomplished by increasing the speed of the rotors (3, 4, 5) while simultaneously reducing the same value for forward rotors (1, 2, 6). For leftward motion the speed of rotors (5 and 6) is increased while the speed of rotors (2 and 3) is reduced.

Backward and rightward motion can be accomplished similarly. Finally, yaw motion can be performed by speeding up or slowing down the clockwise rotors depending on the desired angle direction.

To describe the motion of a 6 DOF rigid body it is usual to define two reference frames (Figure 2):

- the earth inertial frame (E-frame), and
- the body-fixed frame (B-frame).

The equations of motion are formulated using the Newton-Euler laws with the following reasons:

- the inertia matrix is time-invariant;
- advantage of body symmetry can be taken to simplify the equations;
- measurements taken on-board are easily converted to body-fixed frame;
- control forces are almost always given in body-fixed frame.

The E-frame ($O^E xyz$) is chosen as the inertial right hand reference. This frame is used to define the linear position (in meters) and the angular position (in radians) of the quadrotor.

The B-frame is attached to the body. The origin of the B-frame is chosen to coincide with the center of the hexa-rotor microcopter cross structure. This reference is right-hand, too.

The linear position of the helicopter (X, Y, Z) is determi-ned by the coordinates of the vector between the origin of the B frame and the origin of the E-frame according to equation.

The angular position of the hexa-rotor microcopter (Φ, θ, ψ) is defined by the orientation of the E^B-frame with respect to the E^E-frame. This is given by three consecutive rotations about the main axes which take the E^E-frame into the E^B-frame. In this paper, the "roll-pitch-yaw" set of Euler angles (Φ, θ, ψ) were used.

The vector that describes quad-rotor position and orientation with respect to the E-frame can be written in the form:

$$s = [x, y, z, \Phi, \theta, \psi]^T \tag{1}$$

The rotation matrix between the E^E- and E^B-frames has the following from:

$$R = \begin{bmatrix} c\psi c\theta & c\psi s\theta s\Phi - s\psi c\Phi & c\psi s\theta c\Phi + s\psi s\Phi \\ s\psi c\theta & s\psi s\theta s\Phi + c\psi c\Phi & s\psi s\theta c\Phi - c\psi s\Phi \\ -s\theta & c\theta s\Phi & c\theta c\Phi \end{bmatrix} \tag{2}$$

Now, the model of hexa-rotor dynamics can be described by a system of equations:

$$\begin{aligned} \ddot{x} &= (sin\psi sin\psi + cos\psi os\psi sin s\varphi\varphi\frac{U_1}{m} + A_{10} \\ \ddot{y} &= (-cos\psi os\psi s + sin\psi in\psi sin s\varphi\varphi\frac{U_1}{m} + A_{12} \\ \ddot{z} &= -g + cos\theta os\theta c\frac{U_1}{m} + A_8 \\ \ddot{\varphi} &= \frac{I_Y - I_Z}{I_X}\dot{\theta}\dot{\psi} - \frac{J_R}{I_X}\dot{\theta}\omega + \frac{U_2}{I_X}d + A_2 \\ \ddot{\theta} &= \frac{I_Z - I_X}{I_Y}\dot{\varphi}\dot{\psi} - \frac{J_R}{I_Y}\dot{\varphi}\omega + \frac{U_3}{I_Y}d + A_4 \\ \ddot{\psi} &= \frac{I_X - I_Y}{I_Z}\dot{\varphi}\dot{\theta} + \frac{U_4}{I_Z} + A_6 \end{aligned} \tag{3}$$

BACKSTEPPING CONTROLLER FOR HEXA-ROTOR MICROCOPTER

In this paper, controller design for the hexa-rotor microcopter is proposed by using backstepping technique. Backstepping is a recursive design methodology that makes use of Lyapunov stability theory to force the system to follow a desired trajectory. The hexa-rotor microcopter is controlled by angular speeds of six motors. Each motor produces a thrust and a torque, whose combination generates the main trust, the yaw torque, the pitch torque, and he roll torque acting on the hexa-rotor microcopter. First, the dynamical model is rewritten in state-space form:

$$\dot{X} = f(X, U) \tag{4}$$

by introducing :

$$X = [x_1..x_{12}]^T \in \Re^{12} \tag{5}$$

as space vector of the system:

$$\begin{array}{lll} x_1 = \phi & x_5 = \psi & x_9 = Y \\ x_2 = \dot{x}_1 = \dot{\phi} & x_6 = \dot{x}_5 = \dot{\psi} & x_{10} = \dot{x}_9 = \dot{Y} \\ x_3 = \theta & x_7 = X & x_{11} = Z \\ x_4 = \dot{x}_3 = \dot{\theta} & x_8 = \dot{x}_7 = \dot{X} & x_{12} = \dot{x}_{11} = \dot{Z} \end{array} \tag{6}$$

Next, the x- coordinates are transformed into the new z – coordinates:

$$\begin{array}{ll} z_1 = x_{1\_ref} - x_1 & z_7 = x_{7\_ref} - x_7 \\ z_2 = x_2 - \dot{x}_{1\_ref} - \alpha_1 z_1 & z_8 = x_8 - \dot{x}_{7\_ref} - \alpha_7 z_7 \\ z_3 = x_{3\_ref} - x_3 & z_9 = x_{9\_ref} - x_9 \\ z_4 = x_4 - \dot{x}_{3\_ref} - \alpha_3 z_3 & z_{10} = x_{10} - \dot{x}_{9\_ref} - \alpha_9 z_9 \\ z_5 = x_{5\_ref} - x_5 & z_{11} = x_{11\_ref} - x_{11} \\ z_6 = x_6 - \dot{x}_{5\_ref} - \alpha_5 z_5 & z_{12} = x_{12} - \dot{x}_{11\_ref} - \alpha_{11} z_{11} \end{array} \tag{7}$$

By introducing the partial Lyapunov functions [2], to all x – coordinates results in the following backstepping controller:

$$\begin{aligned} U_X &= \frac{m}{U_1}(z_7 - \alpha_7(z_8 + \alpha_7 z_7) - \alpha_8 z_8) \\ U_Y &= \frac{m}{U_1}(z_9 - \alpha_9(z_{10} + \alpha_9 z_9) - \alpha_{10} z_{10}) \\ U_1 &= \frac{m}{\cos x_1 \cos x_3}(z_{11} + g - \alpha_{11}(z_{12} + \alpha_{11} z_{11}) - \alpha_{12} z_{12}) \\ U_2 &= I_{XX}(z_1 - \frac{I_{YY} - I_{ZZ}}{I_{XX}} x_4 x_6 + \frac{J_{TP}}{I_{XX}} x_4 \Omega_r - \alpha_1(z_2 + \alpha_1 z_1) - \alpha_2 z_2) \\ U_3 &= I_{YY}(z_3 - \frac{I_{ZZ} - I_{XX}}{I_{YY}} x_2 x_6 - \frac{J_{TP}}{I_{XX}} x_2 \Omega_r - \alpha_3(z_4 + \alpha_3 z_3) - \alpha_4 z_4) \\ U_4 &= I_{ZZ}(z_5 - \frac{I_{XX} - I_{YY}}{I_{ZZ}} x_2 x_4 - \alpha_5(z_6 + \alpha_5 z_5) - \alpha_6 z_6) \end{aligned} \tag{8}$$

The position of the hexa-rotor microcopter in the earth reference frame is illustrated in Figure 4.

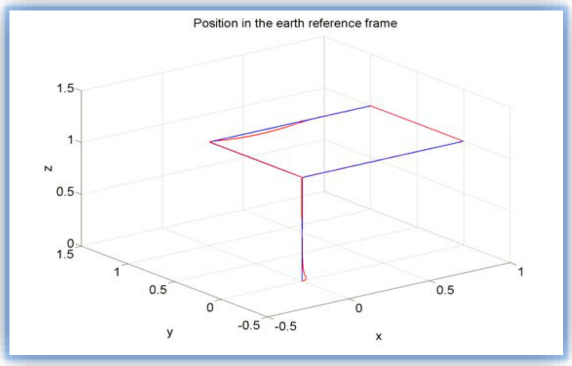

Figure 4. Position of the hexa-rotor microcopter in the earth reference frame.

CONCLUSIONS

This paper presents the development of a dynamic modeling and control algorithm of an autonomous hexa-rotor microcopter. During the last decade many research papers have been published on the topic of modeling and control strategies of autonomous multirotors.

The autonomous hexa-rotor microcopter is an under-actuated and dynamically unstable nonlinear system. The model that represents the dynamic behavior of the hexa-rotor microcopter is complex. Unmanned autonomous aerial vehicles have become a real center of interest. In the last few years, their utilization has significantly increased. The autonomous hexa-rotor microcopters have additional redundancy over autonomous quad-rotor microcopters.

The control design carried out for an autonomous quad-rotor microcopter - backstepping controller, can be applied to the autonomous hexa-rotor microcopter since they are modeled as a rotating rigid body dynamic system wih six degres of freedom.

REFERENCES

[1] Attila Nemes, Genetic Algorithm-Based Adaptive Fuzzy Logic Systems for Dynamic Modeling of Quadrotors, Proceedings of the III[rd] International Conference and Workshop Mechatronics in Practice and Education, MechEdu 2015, pp. 96-103, ISBN 978-86-918815-0-4, Subotica, Serbia, May 14-16, 2015.

[2] Carlos A. Arellano-Muro, Luis F. Luque-Vega, B. Castillo-Toledo, Alexander G. Loukianov, Backstepping Control with Sliding Mode Estimation for a Hexacopter, Proceedings of the 2013 10[th] International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), pp. 31-36, Mexico City, Mexico. September 30 - October 4, 2013.

[3] R. Lozano, Unmanned Aerial Vehicles, ISTE Ltd, London, 2010, ISBN 978-1-84821-127-8

[4] R. Stengel, Flight Dynamics, Princeton University Press, Cloth, 2004, ISBN 0-691-11407-2

[5] G. Carrillo, D. López, R. Lozano, C. Pégard, Modeling the Quadrotor Mini-Rotorcraft, Quad Rotorcraft Control, Springer, 2013, ISBN 978-1-4471-4398-7

[6] Aurélien Yol, Bertrand Delabarre, Amaury Dame, Jean-Émile Dartois and Eric Marchand, Vision-based Absolute Localization for Unmanned Aerial Vehicles, Proceedings of the 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), pp. 3429-3434, 978-1-4799-6934-0/14/$31.00 ©2014 IEEE, September 14-18, 2014, Chicago, IL, USA

[7] Dafizal Derawi, Nurul Dayana Salim, Mohd Azizi Abdul Rahman, Saiful Amri Mazlan, Hairi Zamzuri, Modeling, Attitude Estimation, and Control of Hexarotor Micro Aerial Vehicle (MAV), Proceedings of the 2014 IEEE International Conference on Industrial Technology (ICIT), pp. 55-60, 978-1-4799-3939-8/14/$31.00 ©2014 IEEE, Feb. 26 - Mar. 1, 2014, Busan, Korea.

[8] Nurul Dayana Salim, Dafizal Derawi, Shahrum Shah Abdullah, Saiful Amri Mazlan, Hairi Zamzuri, PID plus LQR Attitude Control for Hexarotor MAV in Indoor Environments, Proceedings of the 2014 IEEE International Conference on Industrial Technology (ICIT), pp. 85-90, 978-1-4799-3939-8/14/$31.00 ©2014 IEEE, Feb. 26 - Mar. 1, 2014, Busan, Korea.

[9] Armando S. Sanca , P. J. Alsina J´es de Jesus F. Cerqueira, Dynamic Modeling with Nonlinear Inputs and Backstepping Control for a Hexarotor Micro-Aerial Vehicle, Proceedings of the 2010 Latin American Robotics Symposium and Intelligent Robotics Meeting, DOI 10.1109/LARS.2010.14, 978-0-7695-4231-7/10 $26.00 © 2010 IEEE, pp. 36 – 42, 2010.

[10] Mark W. Spong, Seth Hutchinson, M. Vidyasagar, Robot Modeling and Control, ISBN-13: 978-0471649908, John Wiley & Sons, Inc, 2006.
[11] Attila Nemes, Synopsis of Soft Computing Techniques Used in Quadrotor UAV Modelling and Control, Interdisciplinary Description of Complex Systems, Vol.13 , No. 1, DOI: 10.7906/indecs.13.1.3, ISSN 1334-4684, pp. 15-25. 2015.
[12] Gyula Mester, Aleksandar Rodic, Autonomous Locomotion of Humanoid Robots in Presence of Mobile and Immobile Obstacles, Studies in Computational Intelligence, Towards Intelligent Engineering and Information Technology, Part III Robotics, Volume 243/2009, pp. 279-293, ISBN 978-3-642-03736-8, DOI 10.1007/978-3-642-03737-5, Springer, 2009.
[13] G. Mester, Obstacle Avoidance and Velocity Control of Mobile Robots, Proceedings of the 6th International Symposium on Intelligent Systems and Informatics SISY 2008, pp. 97-101, ISBN 978-1-4244-2406-1, DOI 10.1109/SISY.2008.4664918, Subotica, Serbia, Sept. 26-27, 2008.
[14] Aleksandar Rodic, Gyula Mester, Virtual WRSN – Modeling and Simulation of Wireless Robot-Sensor Networked Systems, Proceedings of the 8th IEEE International Symposium on Intelligent Systems and Informatics, SISY 2010, pp. 115-120, DOI: 10.1109/SISY.2010.5647245, ISBN: 978-1-4244-7394-6, Subotica, Serbia, 2010.
[15] Gyula Mester, Introduction to Control of Mobile Robots, Proceedings of the YUINFO'2006, pp. 1-4, ISBN 86-85525-01-2, http://www.e-drustvo.org/proceedings/YuInfo2006/html/pdf/188.pdf, Kopaonik, Serbia & Montenegro, 2006.
[16] Aleksandar Rodic, Gyula Mester, Sensor-based Navigation and Integrated Control of Ambient Intelligent Wheeled Robots with Tire-Ground Interaction Uncertainties, Acta Polytechnica Hungarica, Journal of Applied Sciences, Vol. 10, No. 3, pp. 113-133, ISSN 1785-8860, DOI: 10.12700/APH. 10.03.2013.3.9, Budapest, Hungary, 2013.
[17] Aleksandar Rodic, Gyula Mester, The Modeling and Simulation of an Autonomous Quad-Rotor Microcopter in a Virtual Outdoor Scenario, Acta Polytechnica Hungarica, Journal of Applied Sciences, Vol. 8, Issue No. 4, pp. 107-122, ISSN 1785-8860, Budapest, Hungary, 2011.
[18] Ž Hederić, D Šoštarić, G Horvat, Numerical calculation of electro-magnetic forces in magnetic actuator for use in active suspension system for vehicles, Tehnicki Vjesnik-Technical Gazette 20 (1), 73-77.
[19] Simon János, Optimal Microclimatic Control Strategy Using Wireless Sensor Network and Mobile Robot, Acta Agriculturae Serbica Vol. XVIII, No. 36, pp. 3-12, 2013.
[20] Gyula Mester, Sensor Based Control of Autonomous Wheeled Mobile Robots, The Ipsi BgD Transactions on Internet Research, TIR, Volume 6, Number 2, pp. 29-34, ISSN 1820-4503, New York, Frankfurt, Tokio, Belgrade, http://internetjournals.net/journals/tir/2010/July/Paper%2004.pdf, 2010.
[21] Simon János, Goran Martinović, Navigation of Mobile Robots Using WSN's RSSI Parameter and Potential Field Method, Acta Polytechnica Hungarica, Journal of Applied Sciences Vol.10, No.4, pp. 107-118, 2013.
[22] Aleksandar Rodic, Gyula Mester, Modeling and Simulation of Quad-Rotor Dynamics and Spatial Navigation, Proceedings of the SISY 2011, 9th IEEE International Symposium on Intelligent Systems and Informatics, pp 23-28, ISBN: 978-1-4577-1973-8, DOI: 10.1109/SISY.2011.6034325, Subotica, Serbia, 8–10 September, 2011.
[23] Aleksandar Rodic, Milos Jovanovic, Svemir Popic, Gyula Mester, Scalable Experimental Platform for Research, Development and Testing of Networked Robotic Systems in Informationally Structured Environments, Proceedings of the IEEE SSCI2011, Symposium Series on Computional Intelligence, Workshop on Robotic Intelligence in Informationally Structured Space, pp. 136-143, ISBN: 978-1-4244-9885-7, DOI: 10.1109/RIISS.2011.5945779, Paris, France, 2011.
[24] Gyula Mester, Intelligent Wheeled Mobile Robot Navigation, Jelenkori társadalmi és gazdasági folyamatok, V. Évfolyam, 1-2 szám, pp. 258-264, ISSN: 1788-7593, SZTE, Szeged, Hungary, 2010. Gyula Mester, Intelligent Wheeled Mobile Robot Navigation", Konferenciakiadvány Európai Kihívások V, pp. 1-5, SZTE, Szeged, Hungary, 2009.
[25] Sárosi J., Bíró I., Németh J. Cveticanin L., Dynamic Modelling of a Pneumatic Muscle Actuator with Two-direction Motion Mechanism and Machine Theory, Vol. 85, pp. 25-34, 2015.
[26] Aleksandar Rodic, Dusko Katic, Gyula Mester, Ambient Intelligent Robot-Sensor Networks for Environmental Surveillance and Remote Sensing, Proceedings of the IEEE SISY 2009, pp. 28-33, IEEE Catalog Number: CFP0984C-CDR, ISBN: 978-1-4244-5349-8, Library of Congress: 2009909575, DOI 10.1109/SISY.2009. 5291141, Subotica, Serbia, Sept. 25-26, 2009.
[27] Gyula Mester, Simulation of Humanoid Robot Motion, Proceedings of The KANDÓ Conference, pp. 1-8, ISBN 978-963-7154-74-4, Budapest, 2008.
[28] Gyula Mester, Intelligent Mobil Robot Control in Unknown Environments, Intelligent Engineering Systems and Computational Cybernetics, Part I Intelligent Robotics, pp. 15-26, ISBN 978-1-4020-8677-9, Library of Congress: 2008934137, DOI 10.1007/978-1-4020-8678-6_2, Springer, 2009.
[29] Gyula Mester, Szilveszter Pletl, Gizella Pajor, and Imre Rudas. Adaptive Control of Robot Manipulators with Fuzzy Supervisor Using Genetic Algorithms. Proceedings of International Conference on Recent Advances in Mechatronics, ICRAM'95, O. Kaynak (ed.), Volume 2, pages 661–666, ISBN 975-518-063-X, August 14-16, 1995. Bogazici University Bebek, Istanbul, Turkey, †CCA72953/97 ga95aGMester.
[30] Gyula Mester, Obstacle Avoidance of Mobile Robots in Unknown Environments," Proceedings of the 5th International Symposium on Intelligent Systems and Informatics, SISY2007, pp. 123-127, ISBN 978-1-4244-1442-0, DOI 10.1109/SISY.2007.4342637, Subotica, Serbia, August 24-25, 2007.
[31] J. Ćosić, P. Ćurković, Josip Kasać i Josip Stepanić, Interpreting development of unmanned aerial vehicles using systems thinking, Interdisciplinary Description of Complex Systems, Vol. 11, No. 1, pp. 143-152, ISSN 1334-4676, DOI: 10.7906/indecs.11.1.12, 2013.
[32] Stojan Stevanovic, Josip Kasac, Josip Stepanic, Robust tracking control of a quadrotor helicopter without velocity measurement, proceedings of the 23rd International DAAAM Symposium, pp. 595-600, Vienna, Austria 23, 2012.
[33] Josip Stepanic, Gyula Mester, Josip Kasac, Synthetic Inertial Navigation Systems: Case Study of Determining Direction, Proceedings of 57th ETRAN Conference, pp. RO 2.7., 1-3, Zlatibor, Serbia, June 3-6, 2013.

[34] Gyula Mester, Distance Learning in Robotics, Proceedings of The Third International Conference on Informatics, Educational Technology and New Media in Education, pp. 239-245, ISBN 86-83097-51-X, Sombor, Serbia 2006.

[35] Gyula Mester, Improving the Mobile Robot Control in Unknown Environments, Proceedings of the YUINFO'2007, pp. 1-5, ISBN 978-86-85525-02-5, Kopaonik, Serbia, 11-14.03.2007.

[36] Gyula Mester, Szilveszter Pletl, Gizella Pajor, Zoltan Jeges, Flexible Planetary Gear Drives in Robotics, Proceedings of the 1992 International Conference on Industrial Electronics, Control, Instrumentation and Automation - Robotics, CIM and Automation, Emerging Technologies, IEEE IECON '92, Vol. 2, p.p 646-649, ISBN 0-7803-0582-5, DOI: 10.1109/IECON. 1992.254556, San Diego, California, USA, November 9-13, 1992.

[37] Gyula Mester, Szilveszter Pletl: Fuzzy-Neuro Control and its Implementation for a Robot Manipulator. Proceedings of the Teaching Fuzzy Systems Joint Tempus Workshop, pp.1-4, ISBN 963-420-464-3, Budapest, Hungary, 14-16 May, 1995.

[38] Gyula Mester, Adaptive Force and Position Control of Rigid Link Flexible-Joint Scara Robots. Proceedings of the International Conference on Industrial Electronics, Control and Instrumentation, 20th Annual Conference of the IEEE Industrial Electronics Society IECON'94, Vol. 3, pp. 1639-1644, DOI: 10.1109/IECON.1994. 398059, Bologna, Italy, September 1994.

[39] Gyula Mester, Szilveszter Pletl, Imre J. Rudas: Dynamic Modeling of Robot Joints. Proceedings of the IEEE International Workshop on Emerging Technologies and Factory Automation, ETFA'92, pp. 561-565, ISBN 0-646-10323-7, Melbourne, Australia, 08/1992.

[40] Zoltan Rajnai, Edit Szilvia Ruboczki, Moving Towards Cloud Security. Interdisciplinary Description of Complex Systems, Vol. 13, No. 1, pp. 9-14, ISSN 1334-4684, 2015.

[41] Zoltan Rajnai, Bela Puskas, Requirements of the Installation of the Critical Informational Infrastructure and its Management, Interdisciplinary Description of Complex Systems, Vol. 13, No. 1, pp. 48-56, ISSN 1334-4684, 2015.

[42] Livija Cveticanin, Vibration of a Robot Arm, Proceedings of the IIInd International Conference and Workshop Mechatronics in Practice and Education, MechEdu 2015, pp. 31-35, ISBN 978-86-918815-0-4, Subotica, Serbia, May 14-16, 2015.

[43] Branko Karan, Robust position-force control of robot manipulator in contact with linear dynamic environment, Robotica, pp. 799-803, Vol. 23, Issue 06, Cambridge University Press, 2005.

[44] Livija Cveticanin, Gyula Mester, Istvan Biro, Parameter Influence on the Harmonically Excited Duffing Oscillator, Acta Polytechnica Hungarica, Journal of Applied Sciences, Vol. 11, No. 5, pp. 145-160, ISSN 1785-8860, DOI: 10.12700/APH.11.05. 2014.05.9, Budapest, Hungary, 2014.

[45] Simon János, Implementation of potential field method for mobile robot navigation in greenhouse environment with WSN support, Proceedings of the 8th IEEE International Symposium on Intelligent Systems and Informatics, SISY 2010, pp. 319-323, ISBN: 978-1-4244-7394-6, Subotica, Serbia, 2010.

[46] Simon Janos, Goran Martinovic, Web based distant monitoring Intelligent Systems and Informatics, 2009. SISY'09. Proceedings of the 7th IEEE International Symposium on Intelligent Systems and Informatics, SISY'09, pp. 165 – 169, Subotica, Serbia, 2009.

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