

PAPER • OPEN ACCESS

## Modeling and simulation of a dual-axis solar tracker for PV modules

To cite this article: A Marcu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **514** 012036

View the [article online](#) for updates and enhancements.

You may also like

- [A novel method of measuring spatial rotation angle using MEMS tilt sensors](#)  
Jian'an Cao, Xin Zhu, Hao Wu et al.
- [Enhancing solar energy collection with the implementation of a dual-axis tracking system](#)  
Rajendra Singh, Sunil Kumar Gupta and Neeraj Tiwari
- [Dynamic optimization of a dual-axis solar tracker for PV modules](#)  
A Marcu, C Alexandru and I Barbu



**UNITED THROUGH SCIENCE & TECHNOLOGY**

 **The Electrochemical Society**  
Advancing solid state & electrochemical science & technology

**248th  
ECS Meeting**  
Chicago, IL  
October 12-16, 2025  
*Hilton Chicago*

**Science +  
Technology +  
YOU!**

**Register by  
September 22  
to save \$\$**

**REGISTER NOW**

The advertisement features a central image of a smiling woman with long dark hair, wearing a brown blazer, standing against a blue background with a network of white dots and lines. The text is arranged in a clean, modern layout with various font weights and colors (white, blue, orange) to highlight key information.

# Modeling and simulation of a dual-axis solar tracker for PV modules

A Marcu<sup>1</sup>, C Alexandru<sup>1</sup> and I Barbu<sup>1</sup>

<sup>1</sup>Product Design, Mechatronics and Environment Department, Transilvania University of Braşov, Romania

E-mail: calex@unitbv.ro

**Abstract.** The paper deals with the modeling and simulation in virtual prototyping environment of a mechatronic solar tracker used for photovoltaic systems, with the aim to increase the energetic efficiency, by maximizing the rate of incoming incident solar radiation. The solar tracker in study is an equatorial dual-axis mechanism, which allows the adjustment of the diurnal and seasonal angles of the PV module in accordance with a predefined tracking program, the actuating sources being linear actuators. The modeling and simulation of the tracking system is carried out by using the MBS (Multi-Body System) commercial software solution ADAMS (Automatic Dynamic Analysis of the Mechanical Systems).

## 1. Introduction

This paper addresses a topic from a very important field: renewable sources for the generation of electricity - increasing the efficiency of conversion in solar panels. Research in this area represents a global priority as it provides viable alternatives to a series of major problems the mankind is facing: the limiting and polluting nature of conventional sources, global warming, or greenhouse effect.

The sun represents the most important source of renewable energy, the current systems allowing the conversion of the solar energy into electricity or heat. The energy efficiency of the solar panels depends largely on the solar energy capture, which can be maximized by using systems for the orientation of the panels towards the sun. The orientation principle of the solar panels is based on the data regarding the position of the sun on the celestial sphere. To ensure the greatest possible efficiency of the solar energy conversion into electricity, the sun rays must fall normally on the surface of the receiver, so it is necessary that the system periodically modifies its position in such a way as to maintain the relationship between the sun rays and the panel [1-3]. On the one hand, over the course of one year, the Earth describes an elliptical rotation movement around the Sun, and on the other hand, over the course of a day, it performs a complete rotation around its own axis (a movement that generates sunrises and sunsets). Therefore, for the design of the solar tracking systems, both rotating movements have to be taken into consideration: the diurnal movement and the seasonal (elevation) movement [4, 5].

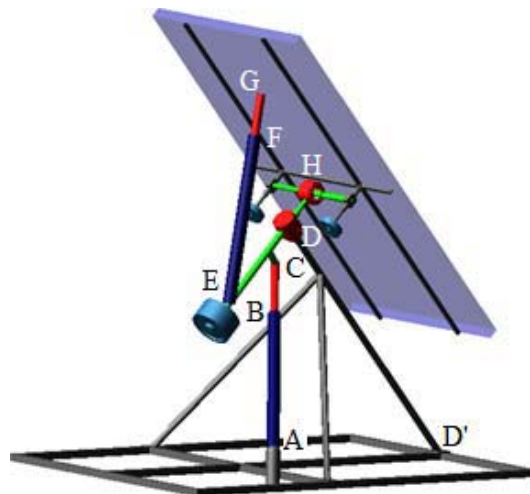
As the complexity and competitiveness of the development of the tracking systems grows, the design and production times are reduced, conditions in which the creation and testing of physical prototypes become major impediments to launching new products. Therefore, it is necessary to implement techniques based on virtual prototyping that can deliver higher performance and product quality using only a fraction of the time and cost required in the traditional creation and testing approaches [6-11].



## 2. Modeling the solar tracking mechanism

For this paper, an equatorial dual-axis tracking mechanism was considered, whereby the necessary movements are generated by means of two linear actuators. Its operation is done in steps, the movement/positioning laws of the panel being modeled to achieve a minimum number of actuations (for energy efficiency purposes). The kinematic model of the tracking system concerned, having two degrees of freedom, contains the bodies in the system, connected by kinematic joints (geometric constraints), and the geometric parameters specific to the mechanism (locations/orientation of the joints). The input (operation) is made by kinematic constraints (motion generators) applied in the translation joints between the pistons and the linear actuator cylinders.

The tracking mechanism considered includes two kinematic chains to generate the two necessary movements, namely the kinematic chain for diurnal movement (ABCD) and the kinematic chains for the seasonal movement (EFGH) respectively. The geometric constraints in A, C, D and E, G, H respectively, are modeled by revolute joints, while the B and F are modeled by translation joints. In order to achieve the diurnal movement, the panel rotates relative to the support element around the axis D-D', while the seasonal movement of the panel is made by rotation of the support element relative to the supporting pillar around the H joint axis.



**Figure 1.** The MBS model of the equatorial dual-axis tracking system.

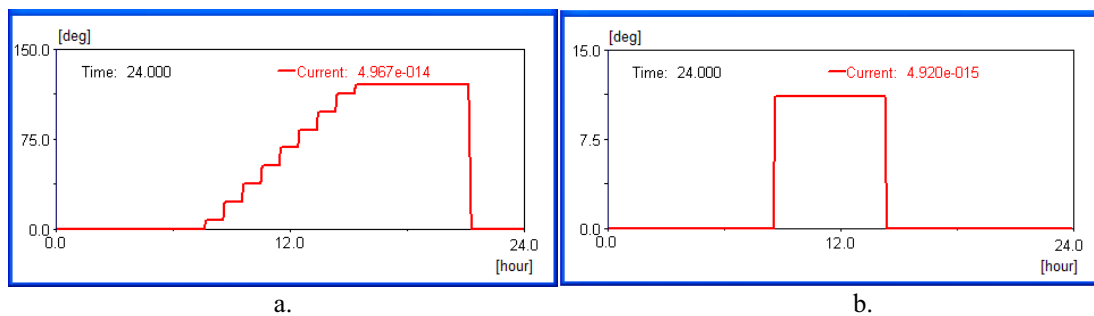
The angular movements of the panel can be done continuously or in steps. For energy efficiency reasons of the system, the movement is chosen to be made in steps, the movement laws of the panel, for both rotations, being set so as to achieve a minimum number of actuations; the simulation is made considering the data specific to the summer solstice and the latitude of the Braşov area, which actually determine the orientation of the panel relative to the position of the sun on the celestial sphere.

In terms of diurnal movement, the total angle achieved by the panel is  $120^\circ$  ( $-60^\circ$ , ...,  $+60^\circ$ ), with the zero position (at noon), while for the seasonal position the elevation angle is adjusted from  $11^\circ$  to  $22.05^\circ$ . In the virtual model created by using the MBS ADAMS software, the movement laws of the panel were modeled by summing a series of STEP time functions as follows:

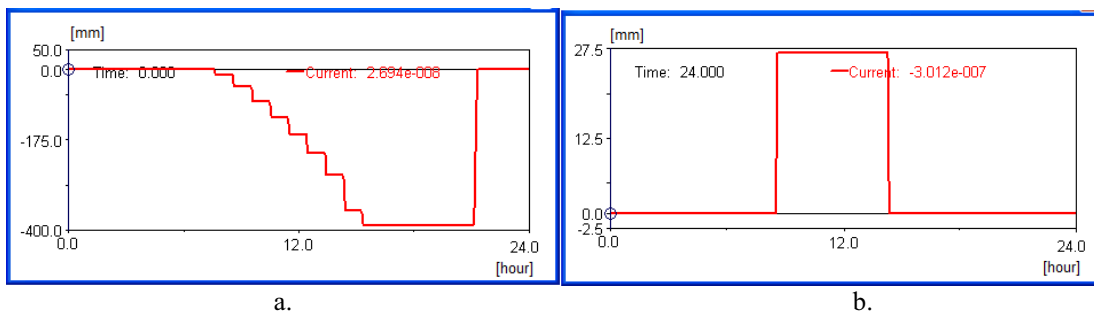
- for the diurnal movement:  
 $\text{STEP}(\text{time}, 0.0, 0.0\text{d}, 4.26, 0.0\text{d}) + \text{STEP}(\text{time}, 4.26, 0.0\text{d}, 7.91, 0.0\text{d}) + \text{STEP}(\text{time}, 7.91, 0.0\text{d}, 8.01, 7.5\text{d}) + \text{STEP}(\text{time}, 8.91, 0.0\text{d}, 9.01, 15.0\text{d}) + \text{STEP}(\text{time}, 9.91, 0.0\text{d}, 10.01, 15.0\text{d}) + \text{STEP}(\text{time}, 10.91, 0.0\text{d}, 11.01, 15.0\text{d}) + \text{STEP}(\text{time}, 11.91, 0.0\text{d}, 12.01, 15.0\text{d}) + \text{STEP}(\text{time}, 12.91, 0.0\text{d}, 13.01, 15.0\text{d}) + \text{STEP}(\text{time}, 13.91, 0.0\text{d}, 14.01, 15.0\text{d}) + \text{STEP}(\text{time}, 14.91, 0.0\text{d}, 15.01, 15.0\text{d}) + \text{STEP}(\text{time}, 15.91, 0.0\text{d}, 16.01, 7.5\text{d}) + \text{STEP}(\text{time}, 16.01, 0.0\text{d}, 18.46, 0.0\text{d}) + \text{STEP}(\text{time}, 18.46, 0.0\text{d}, 22.0, 0.0\text{d}) + \text{STEP}(\text{time}, 22.0, 0.0\text{d}, 22.2, -120.0\text{d}) + \text{STEP}(\text{time}, 22.2, 0.0\text{d}, 24.0, 0.0\text{d});$

- for the seasonal (elevation) movement:  
 $\text{STEP}(\text{time}, 0.0, 0.0\text{d}, 4.26, 0.0\text{d}) + \text{STEP}(\text{time}, 4.26, 0.0\text{d}, 8.91, 0.0\text{d}) + \text{STEP}(\text{time}, 8.91, 0.0\text{d}, 9.01, 11.05\text{d}) + \text{STEP}(\text{time}, 9.01, 0.0\text{d}, 14.91, 0.0\text{d}) + \text{STEP}(\text{time}, 14.91, 0.0\text{d}, 15.01, -11.05\text{d}) + \text{STEP}(\text{time}, 15.01, 0.0\text{d}, 18.46, 0.0\text{d}) + \text{STEP}(\text{time}, 18.46, 0.0\text{d}, 24.0, 0.0\text{d})$

In these terms, the time variation laws of the diurnal and seasonal angles are presented in Figure 2 (relative to the initial position, at 4.26 hours, where  $\varphi_d = 60^\circ$ ,  $\varphi_s = 11^\circ$ ). On the basis of these laws applied to the revolute joints in D (diurnal movement) and H (seasonal movement), according to the notations in Figure 1, the transposed/equivalents for the linear displacements of the actuators were obtained (the relative movement of the pistons relative to the cylinders), actually the kinematic constraints applied to the translation joints in B (diurnal movement) and H (seasonal movement), for which time variation diagrams are shown in Figure 3 (a - diurnal motion, b - elevation motion).



**Figure 2.** The time-history variations of the daily (a) and elevation (b) angles.

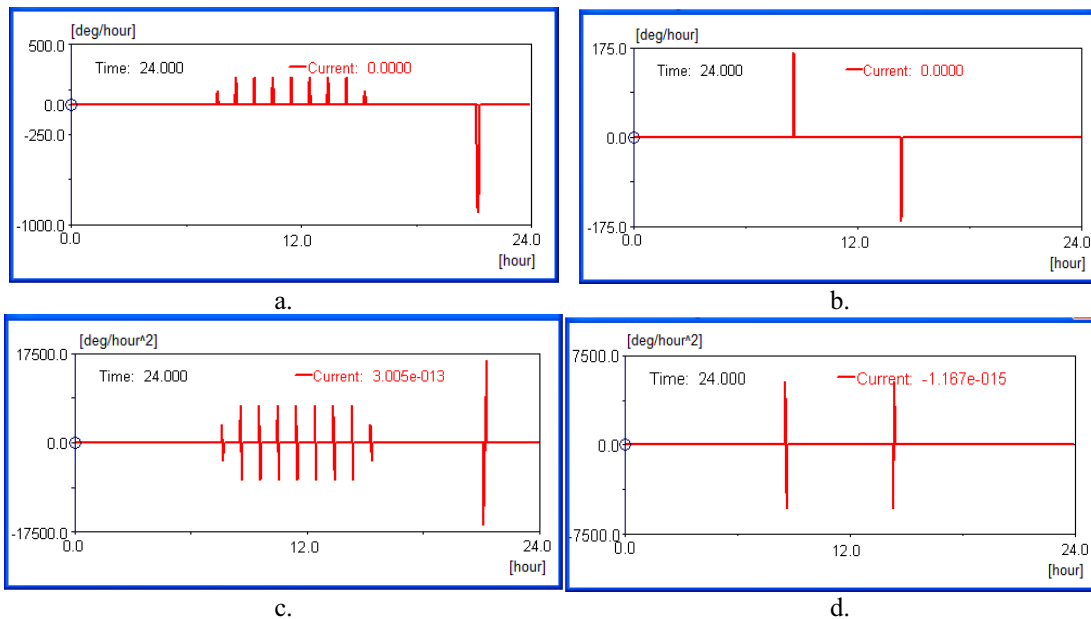


**Figure 3.** The time-history variations of the actuators strokes.

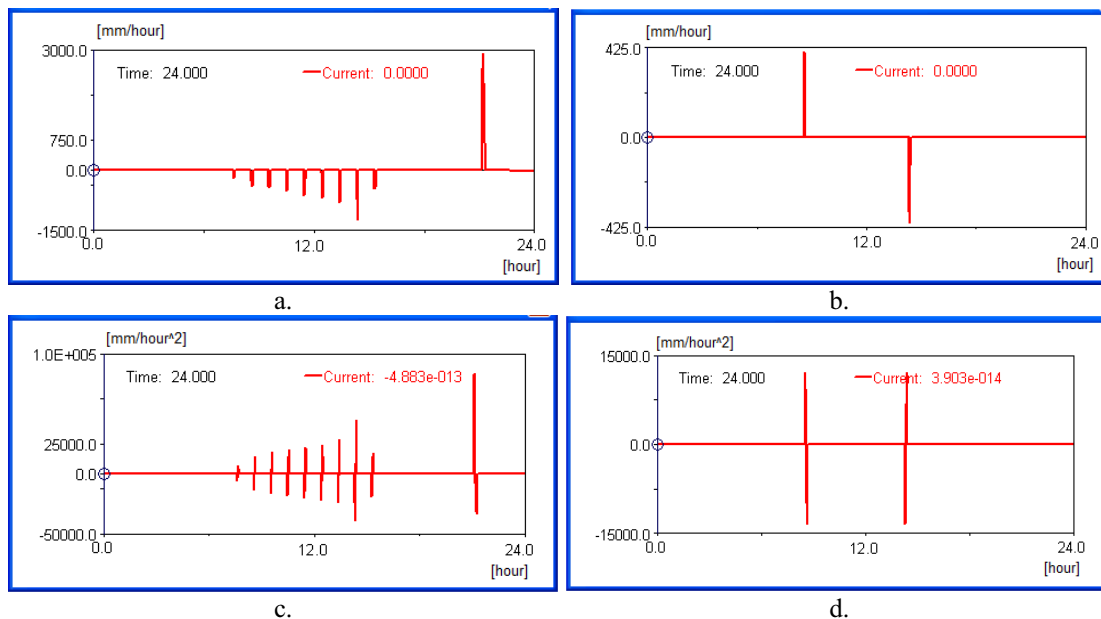
### 3. Results and conclusions

The kinematic model processing is done by launching the ADAMS/Solver module, which auto-formulates and solves the kinematic motion equations. Following the model analysis, the behavior of the tracking system is determined, for whose evaluation the post-processing of the results is further carried out. Post-processing consists in plotting variation diagrams for the values of interest (positions, velocities, accelerations), graphic animations, and others. For example, Figure 4 shows the angular velocities (a - diurnal motion, b - elevation) and accelerations (c - diurnal motion, d - elevation) for the two panel movements, and Figure 5 shows the linear velocities (a - diurnal motion, b - elevation) and accelerations (c - diurnal motion, d - elevation) in the actuators.

The results obtained demonstrate that the designed tracking system fulfills the movement functions, ensuring the necessary positioning of the panel for the whole functioning cycle (no self-lockings of the mechanism show up). Further on, by means of the reverse dynamic analysis, the driving forces are determined, which, when applied to the leading elements of tracking system charged with forces, they generate the prescribed kinematic behavior. The driving forces represent the input data into the direct dynamic model, and then the tracking system behavior under the action of the forces is to be assessed.



**Figure 4.** The time-history variations of the angular velocities (a, b) and accelerations (c, d).



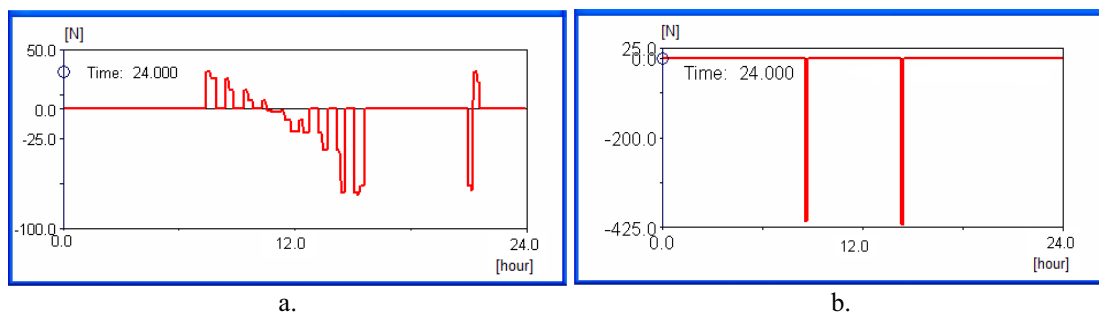
**Figure 5.** The time-history variations of the linear velocities (a, b) and accelerations (c, d).

The tracking system concerned has two degrees of freedom, namely the linear displacements in the actuators (which generate the two movements of the panel), which in the kinematic model are controlled (imposed) by kinematic constraints of the form  $S(t)$  whose variation laws have been shown in Figure 3. In the case of the dynamic model, the kinematic constraints are replaced by driving forces, so that the system has two generalized independent coordinates.

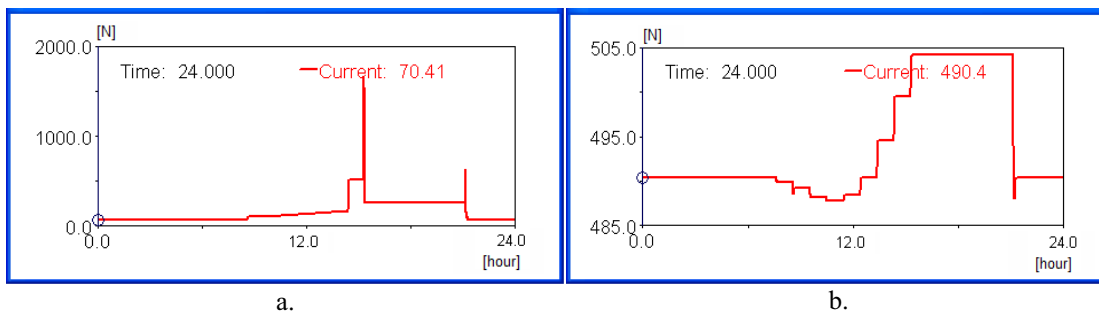
The inverse dynamic model of the tracking system includes, on the one hand, the components specific to the kinematic model (the bodies, the links between them, the specific geometric

parameters) and, on the other hand, the external and internal system of forces which engage the mechanism. The charging of the tracking system concerned is done by mass forces only (other forces may also be considered, such as the action of the wind, etc.). Thus, the values of the driving forces in the linear actuators are obtained, the time variations being shown in the diagrams in Figure 6 (a - diurnal motion, b - elevation). The driving forces thus obtained represent inputs into the direct dynamic model of the tracking system, replacing the kinematic constraints in the kinematic model.

The dynamic model evaluates the behavior of the system under the action of the forces. As an example, Figure 7 shows the results of the dynamic analysis on the magnitude of the reaction forces in the revolute joints A (Fig. 7, a) and E (Fig. 7, b) of the actuator cylinders to the adjacent elements (see Figure 1). Such reactions are necessary for the drawing of the engagement schemes, for the dimensioning of the joints and of the elements of the mechanism.



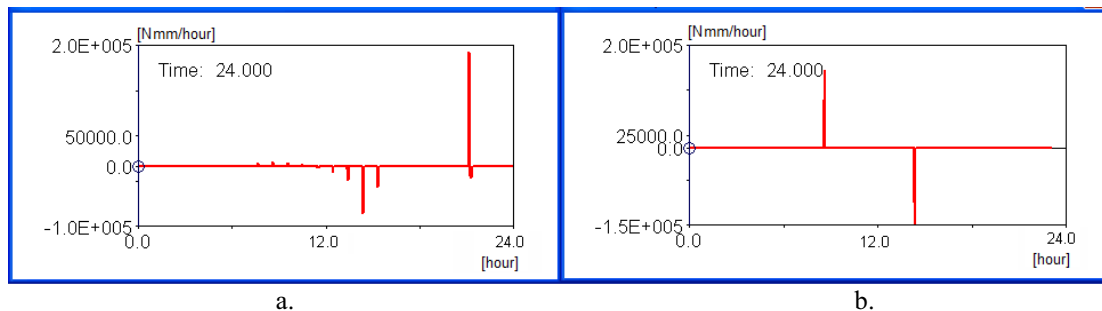
**Figure 6.** The motor forces in actuators.



**Figure 7.** The reaction forces in the revolute joints A and E.

In the case of the joints in the kinematic chain for the diurnal movement (ABCD contour), there was a large increase in the reactions caused by the swing/ sudden rotation of the actuator within a very short interval, for kinematic reasons. Except for this interval, the variation is relatively low, as it can be observed from the time variation diagram of the A joint reaction (similar to the other joints). The reported problem will be subject to dynamic optimization of the tracking system, which is presented in another paper submitted to the Xth Product Design, Robotics, Advanced Mechanical & Mechatronic Systems and Innovation Conference - PRASIC [12].

On the other hand, Figure 8 shows the time variation diagrams for power consumption in order to achieve the desired movements (diurnal and seasonal/elevation), a very important parameter for assessing the energy efficiency of the tracking system. Maximum consumption occurs on the return area through continuous movement (without steps) to the initial position at the end of the day. Except for this area, the maximum occurs over the overlapping of the two movements/rotations in the 14.91-15.01 time slot, as well as over the sudden tilting/rotation of the diurnal actuator (problem which was reported for the reactions in the joints).



**Figure 8.** The power consumption for the diurnal (a) and elevation (b) motions.

Along with the development of the MBS method and software, the design of the tracking systems evolved in a new direction: the design and analysis of complex theoretical models, close to actual models both in terms of system structure as well as operating conditions. True virtual prototypes for the tracking systems can be designed with the help of the MBS software platforms, considering reducing to the minimum the expenditures that would result from designing physical prototypes as well as the time required for testing. Regarding the equatorial tracking system concerned, although from a kinematic point of view, its behavior followed the required movement functions, some dynamic problems (strong reactions in joints, high power consumption) have been identified, which are to be eliminated based on a study of dynamic optimization [12].

## References

- [1] Alexandru C 2009 The design and optimization of a photovoltaic tracking mechanism *Proceedings of the 2nd IEEE International Conference on Power Engineering, Energy and Electrical Drives POWERENG 2009* pp 436-441
- [2] Alexandru C and Tatu I N 2013 Optimal design of the solar tracker used for a photovoltaic string *Journal of Renewable and Sustainable Energy* **5** pp 1-16
- [3] Altuzarra O, Macho E, Aginaga J and Petuya V 2015 Design of a solar tracking parallel mechanism with low energy consumption *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* **229** pp 566-579
- [4] Edgar R, Stachurski Z and Cochar S 2016 Optimisation direct normal insolation of rectangular PV platforms *Solar Energy* **136** pp 166-173
- [5] Ioniță M and Alexandru C 2012 Dynamic optimization of the tracking system for a pseudo-azimuthal photovoltaic platform *Journal of Renewable and Sustainable Energy* **4** pp 1-15
- [6] Alexandru C and Pozna, C 2009 Dynamic modeling and control of the windshield wiper mechanisms *WSEAS Transactions on Systems* **8** pp 825-834
- [7] Alexandru C and Alexandru, P 2010 The virtual prototype of a mechatronic suspension system with active force control *WSEAS Transactions on Systems* **9** pp 927-936
- [8] Alexandru C and Alexandru, P 2011 A comparative analysis between the vehicles' passive and active suspensions *International Journal of Mechanics* **5** pp 371-378
- [9] Alexandru P, Macaveiu D and Alexandru C 2012 Design and simulation of a steering gearbox with variable transmission ratio *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* **226** pp 2538-2548
- [10] Bernard A 2005 Virtual engineering: methods and tools *Journal of Engineering Manufacture* **219** pp 413-421
- [11] Tarniță D, Marghitu D 2013 Analysis of a hand arm system *Robotics and Computer-Integrated Manufacturing* **29**, pp 493-501
- [12] Marcu A, Alexandru C and Barbu I 2018 Dynamic optimization of a dual-axis solar tracker for PV modules *Proceedings of the Xth Product Design, Robotics, Advanced Mechanical & Mechatronic Systems and Innovation Conference PRASIC 2018*