

# Dynamic Modeling and Control of Cleaning Robot for Agro Photovoltaic

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## ABSTRACT

In this paper, modeling and control of a robotic carrier for the cleaning system of solar farms are presented. Since solar panels are placed in natural environments, there is always a problem of dust accumulation on the panels, which results in absorbed energy reduction. Hence, robotic cleaners can be used for solar panels. For relocation of the cleaning robot between solar panel rows, an automated carrier mechanism is required. Hence, a robotic system for cleaner displacement is introduced, and its dynamics modeling and control is presented. The robot kinetics and kinematics models have been derived and validated by ADAMS software. Hence, kinetics and kinematics model-based controllers are introduced for robot motion control. Using the kinetics model, a CTM (Computed Torque Method) controller is designed and simulated. For less computational efforts, a TJ (Transposed Jacobian) controller is designed, using the kinematics model. Finally, to increase control performance, an MTJ (Modified TJ) controller is also designed. The desired trajectory is designed for the robot. Finally, for software verification and analysis, the controllers are simulated, using co-simulation of MATLAB Simulink and ADAMS model. The simulation results show the satisfactory performance of the controllers and can be used for further design analysis of the prototype.

## KEYWORDS

Cleaner robot photovoltaic panels, APV, Dynamics modelling, Model base control, simulation.

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## 1. Introduction

Solar power is one of the most important energy sources in the world. One major problem that reduces the energy efficiency of solar panels is the dust accumulation on the panels. This problem gets worse for AgroPhotoVoltaic (APV) systems, in which solar panels are placed at the agricultural sites. These systems are used where land is scarce and very valuable; and also, where the plants need to have a shelter or a partial shadow against the direct sunlight, [1-2].

To avoid deficiency, the panels must be cleaned in regular plans. This cleaning is a difficult maintenance task for large solar farms, with many long rows of solar panels, considering the high risks of electric shocks for the workers and damaging of the panels. Furthermore, due to very wide area, the quality of cleaning is usually low, and sometimes a lot of water is required, or heavy machinery is used, as depicted specifically, where very wide panels are placed at higher heights, specific machinery is required, which might have heavy and low flexible arms that can damage the panels, [3-4]. Exploiting light, small, and smart robotic cleaning systems, the maintenance process can be done automatically or remotely controlled, with higher task qualities and without human safety risks. Furthermore, a longer lifecycle of panels and less water consumption may be achieved. Using such automatic systems regularly, dust, snow, and birds' faces and corps can be removed. Even in dry areas, studies have shown that up to 15% of energy loss due to the mentioned problems, [5-6].

Many designs have been presented for solar panel cleaning robots, [7]. Some robots can move on the panels, [8], while some others move on the ground or rails and clean the panels all along their path, [9-10]. In most solar farms, the panels are placed in rows of tens or hundreds of meters. Typically, each row of panels has its robot. The main reason is the difficulty of robot transportation between the rows. To overcome this problem, a different carrier robotic system can be used, to transfer the cleaner between the rows, [11-12]. The rows are typically placed adjacently, and it is possible to place passage beside them for such a carrier robot.

In this paper, as a part of the initial design of the robotic maintenance system, the kinematics and dynamics model of the carrier robot is presented. The initial design of the robotics system is briefly presented. Then, kinematics and kinetics modeling of the robot are presented. In section two, the derived model is validated, using ADAMS software. For the validation, after the validation, in section three, a controller is designed for the robot. The controlled robot is simulated using MATLAB Simulink and ADAMS co-simulation. The results show that the proposed system is capable of the desired tasks. These results are also used for finalizing the design, before manufacturing the robotic system. In the next section, model based controllers of the robotic system. This study is used to analyze the performance and the requirements of the prototype, before its manufacture. The robot kinetics and

kinematics models have been modeled both mathematically and by ADAMS. According to the required conditions and consideration of solar farms, the robot must work accurately, following proper trajectories. Hence, model-based controllers can be good choices for this system. In section four, the kinematics model is used to design a TJ controller. The controller is designed and simulated for tracking the planned trajectory. Then, to improve the control results, an MTJ controller is designed and simulated. In section five, to achieve better results, with the expense of more computational efforts, a CTM controller is designed as a kinetics model-based controller. All controllers are simulated and verified using the co-simulation of MATLAB Simulink and ADAMS model, [13-14]. Finally, the controller performances are presented and the results are compared.

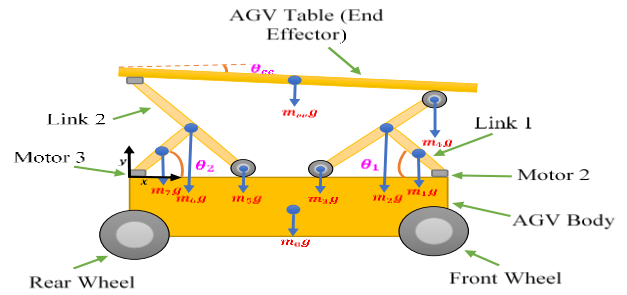


Figure 1. Schematic of the system with geometric specifications

## 2. Methodology

### 2.1. Dynamics Modeling

In this section, the dynamics modeling of the robot is presented. The kinematics variables are introduced, The robot has three degrees of freedom, including moving forward and backward on a rail; and two degrees for height adjustment of the front and rear scissors. Based on the motor placement,  $(x, \theta_1, \theta_2)$  can be chosen as the inputs of the control system, or as the general coordinates. Regarding the final task, the position of the table -considered as the robot End Effector- the control output or the general coordinates can be considered as  $(x_{ee}, y_{ee}, \theta_{ee})$ .

### 2.2. System kinematics

For kinetics and kinematics modeling, the position of mass centers and orientation of all parts are required. Hence, using the geometry, orientation and center position of all robot parts are as follows. It should be noted that the robot body is referred to as link 0. The Jacobian matrices for x,y position of links are derived as follows, where  $v$  refers to linear velocity. Likewise, the Jacobian matrices for orientations of the links where,  $\omega$  refers to angular speeds. Hence, the mass center velocity  $v_i$  and angular velocity  $\omega_i$  of each link. Using the Jacobian matrices, the velocities can be determined for the table and for other parts, to present a complete kinematics model. It should be noted that the inertia of the wheels are negligible compared to other masses, and

their angular speed are also small. Hence,  $\dot{\theta}_3$ ,  $\dot{\theta}_4$ ,  $\dot{\theta}_5$  are not important for dynamics modeling.

### 2.3. Dynamic Model Validation

In this section, the derived dynamics model is validated using software simulation. For software simulation, ADAMSTM is used. The robot is modeled in the software, as represented the Fig. 2 (up). For comparison, the ADAMS model is exported to MATLAB Simulink as in Fig. 2 (down). For validation, four robot motions were simulated. For each motion simulation, a predefined motion is given to the ADAMS model, as the input. Then, the required motor forces/torques are read as the simulation output. Finally, the results are compared with the model from, [17]. In order to use ADAMS simulator, first, the models of all robot links is built in the software, including mass and inertia and dimension of each link. Then, all of the constraints, forces, torques and motions must be defined and added to the model. Since our model calculations are performed in MATLAB, the ADAMS model is exported to MATLAB Simulink.

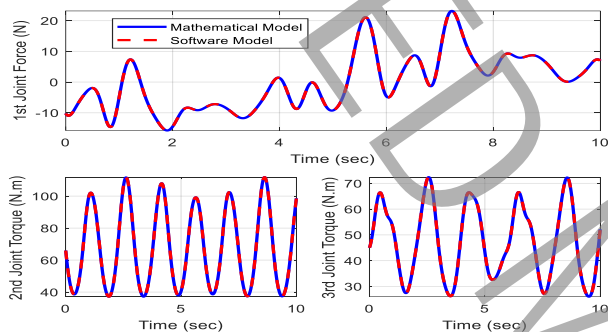


Figure 2. Comparison of modeling results in ADAMS software and extracted dynamic equations

### 3. Conclusion

This paper presented modeling and control of a robotic transportation system, for the cleaner unit used in solar farms. First, the system geometry, its parameters, and the kinematics modeling were presented. Then, the Lagrange method was used to derive the dynamics model of the robot. For validation, the robot was also modeled in ADAMS. The results achieved from ADAMS and the presented dynamics models were compared. The main reasons for this robot modeling are to study the robot performance for prototype design and also the design of its motors, based on its performance in a control task. Hence, after modeling, a PID controller was proposed and designed, for position control of the robot. The kinetics and kinematics models were introduced, to be used in the model-based controllers. Based on the robot properties, the desired trajectory was designed for the robot motion, between two adjacent solar panel rows. First, a TJ controller was designed based on the kinematics model. The controller presented satisfactory results. However, the steady-state errors could not be eliminated. Thus, an MTJ controller was introduced and designed. Using the MTJ method, the steady-state errors were eliminated, with minimum

computational costs. Then, to achieve perfect performance, a kinetics model was used for control. Hence, a CTM controller was presented and designed. This method is a feedback linearization method, which shows great performance with the cost of computational efforts for the kinetics model. The simulation results showed great performance for this controller.

### 4. References

- [1] E. De Schepper, S. Van Passel, J. Manca, T. Thewys, Combining photovoltaics and sound barriers—A feasibility study, *Renewable energy*, 46 (2012) 297-303.
- [2] C. Dupraz, H. Marrou, G. Talbot, L. Dufour, A. Nogier, Y. Ferard, Combining solar photovoltaic panels and food crops for optimising land use: towards new agrivoltaic schemes, *Renewable energy*, 36(10) (2011) 2725-2732.
- [3] A. Syafiq, A. Pandey, N. Adzman, N. A. Rahim, Advances in approaches and methods for self-cleaning of solar photovoltaic panels, *Solar Energy*, 162 (2018) 597-619.
- [4] N. M. Kumar, K. Sudhakar, M. Samykano, S. Sukumaran, Dust cleaning robots (DCR) for BIPV and BAPV solar power plants-A conceptual framework and research challenges, *Procedia Computer Science*, 133(2018) 746-754.
- [5] J. Burgaleta, A. Ternero, D. Vindel, I. Salbidegoitia, G. Azcarraga, Gemasolar, key points for the operation of the plant, *SolarPACES, Marrakech*, (2012).
- [6] S. Bushong, Robot Cleans Solar Panels And Protects Efficiency, *Dust Wars*, (2013).
- [7] D. Deb, N. L. Brahmabhatt, Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution, *Renewable and Sustainable Energy Reviews*, 82 (2018) 3306-3313.
- [8] A. Saini, A. Nahar, A. Yadav, D. S. Shekhawat, M. A. Vijayvargiya, Solar Panel Cleaning System, 3(5) (2017).
- [9] A. K. Mondal, K. Bansal, A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels, *Advanced Robotics*, 29(8) (2015) 515-524.
- [10] Serbot Swiss Innovations. GEKKO Solar Robot; [cited 2019 Aug]. Available from: <http://WWW/en/solar-panels-cleaning/gekko-solar-robot>." (accessed).
- [11] M. Anderson, Robotic device for cleaning photovoltaic panel arrays, in *Mobile Robotics: Solutions and Challenges*: World Scientific, (2010) 367-377.
- [12] Ecoppia. EMPOWERING SOLAR; [cited 2019 Aug]. Available from: <http://WWW/products-and-services/>." (accessed).
- [13] M. A. Jaradat, A fully portable robot system for cleaning solar panels, in *2015 10th International Symposium on Mechatronics and its Applications (ISMA)*, (2015) 1-6.
- [14] D. C. Tranca, D. Rosner, A. V. Palacean, Autonomous flexible low power industrial IoT controller for solar panels cleaning systems, in *2017 21st International Conference on Control Systems and Computer Science (CSCS)*, (2017) 106-112.
- [15] H. Wang, W. Ren, C. C. Cheah, Y. Xie S. Lyu, Dynamic Modularity Approach to Adaptive Control of Robotic Systems With Closed Architecture, *IEEE Transactions on Automatic Control*, 65(6) (2020) 2760-2767.
- [16] O. Christidi-Loumpasefski, G. Rekleitis, E. Papadopoulos, Concurrent Parameter Identification and Control for Free-Floating Robotic Systems during On-Orbit Servicing, *IEEE International Conference on Robotics and Automation (ICRA)*, Paris, France, (2020).
- [17] John J. Craig, Introduction to Robotics Mechanics and Control. 3rd ed., (2018).