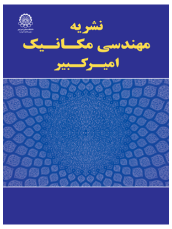

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Dynamic modeling and control of cleaning robot for agro-photovoltaic

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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 are 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 computed torque method controller is designed and simulated. For less computational effort, a transposed Jacobian controller is designed, using the kinematics model. Finally, to increase control performance, an modified transposed Jacobian 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.

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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 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,

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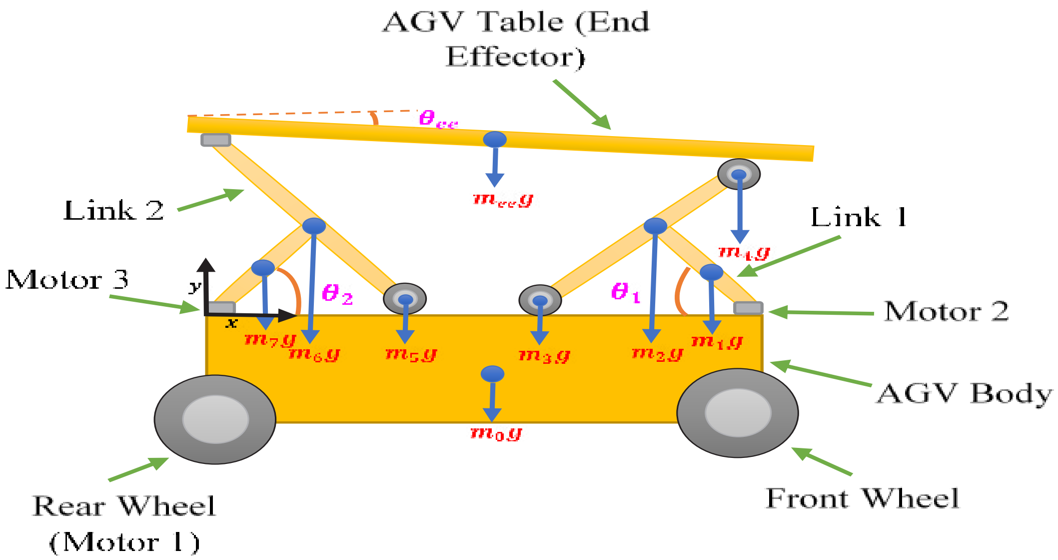

Fig. 1. Schematic of the system with geometric specifications

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 Transposed Jacobian (TJ) controller. The controller is designed and simulated for tracking the planned trajectory. Then, to improve the control results, a Modified Transposed Jacobian (MTJ) controller is designed and simulated. In section five, to achieve better results, with the expense of more computational efforts, a Computed Torque Method (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.

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, θ_1, θ_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}.θ_{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 positions of links are derived as follows, where v refers to linear velocity. Likewise, the Jacobian matrices for orientations of the links where, ω refers to angular speeds. Hence, the mass center velocity v_i and angular velocity ω_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, ADAMS™ 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 are 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.

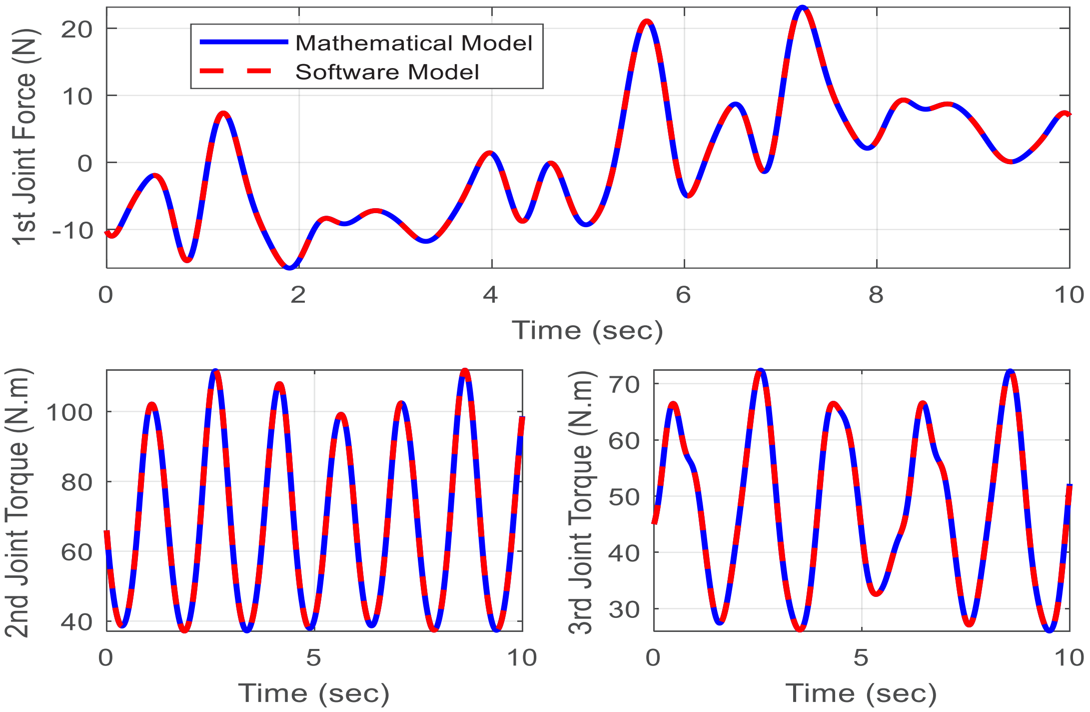

Fig. 2. Comparison of modeling results in ADAMS software and extracted dynamic equations

3- Conclusions

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.

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