A PHOTOVOLTAIC POWERED TRACKING SYSTEM FOR MOVING OBJECTS

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ABSTRACT

The paper presents a novel position control scheme using a photovoltaic powered position tracking system for moving targets. The system consists of two different stages as catching and tracking. A Fuzzy logic controller (FLC) is designed to control the system. The performance of the FLC is compared with that of a PI controller.

I. INTRODUCTION

Photovoltaic PVA-solar powered electrical systems comprise different components and subsystems to be controlled separately. Since the generated solar power is dependant on uncontrollable environmental conditions, it requires extra caution to design controllers that handle unpredictable events and maintain efficient load matching power. In this study, a photovoltaic (PV) solar array model developed for Matlab/Simulink GUI environment [1] is used to supply power to the tracking system, which is controlled using a fuzzy logic controller (FLC). The tracking system is assumed to be a mobile and can be used as an outdoor device without worrying about the power source. System is modeled having solar photovoltaic (PV) power source and backup batteries to maintain a continuous operation.

The motorized PV powered tracking control system proposed here can be mounted on any moving vehicle, which can be either parked or in the move. The chosen target to be tracked has a relative speed with respect to the vehicle carrying the tracking system. The moving target system here may be a car, a tank, artillery, a bus, a train, or a boat. The system can also be used in security systems such as protecting a large area or farm against the intruders. The moving target may also be a submarine or an aircraft. However, in the case of an aircraft or a submarine, the tracking system should be able to move in three dimensions, since these objects move up, down, forward, and backward. In this study, it is assumed that, the object is moving very fast on a road or on a surface with a straightforward direction all the time. Therefore, the tracking system must keep moving along with the target object after they are locked. If any speed change occurs in moving object, then the tracker must move with the same speed in order not to loose tracking. The object may accelerate or decelerate in the same direction and on the same surface level. The tracker is supposed to catch and track the moving object as it speeds up or down.

An error driven fuzzy logic controller (FLC) is designed in Matlab/Simulink environment and combined with all the other component models. The FLC model used in this study is a novel Simulink model represented by the basic operational blocks in Simulink and operates independently from the built in Fuzzy Logic (FL) Toolbox of the Simulink. With the proposed FLC model, the user does not have to model the physical system to fit the built in specifications of the built in FL Toolbox. Instead, the user has the flexibility to modify the FLC to fit the physical system.

This paper has a couple of contributions:

1. Simulation model of the Photovoltaic PV array in Simulink environment,
2. Modelling and simulation of tracking system,
3. A novel Simulink modelling of FLC and its utilization with the tracking system.

II. THE TRACKING SYSTEM

The principle diagram of the system to be studied is shown in Fig. 1. The system consists of a radar receiver, an amplifier, a permanent magnet direct current (PMDC) motor driven tracking system, and a PV solar array as the power source. All the system gets its required power from the PV array as described in the next section. The tracking system with all components is either mounted on a standstill base or mounted on a moving chart. The first case with a conventional DC source has been studied earlier [2]. The second is a little bit different than the first one such that the second case deals with the relative position between tracking device and the object while the first case deals with the position of the object only since the position of the tracking device is fixed. Both cases are analysed and simulated here. The second case requires additional information such as the position of the cart or vehicle that is carrying the tracker. However, the position of the vehicle carrying the tracker may not be required if the modelling is established based on the relative position of the moving object with respect to the vehicle carrying the tracker. Since there are two moving objects, the relative position becomes a nonlinear problem if both objects have different speeds. The nonlinearity can be solved by assuming the position of one of the moving objects most likely the vehicle that is carrying the tracker as the reference position. The nonlinear relative position can be referred to the reference position with a similar approach used in rotating machines to solve the flux or voltage equations in a reference frame [3]. In this paper, the position of the vehicle carrying the tracker is assumed to be the reference position and the position of the other moving object is obtained with respect to the tracker's position.

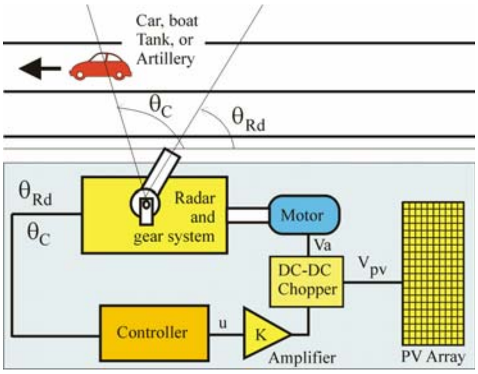

Figure 1. Schematic diagram of the tracking control system

In the proposed system, the motor and the radar are coupled together over a gear system. The radar is supposed to track the moving target. The radar system is used to determine the relative position of the moving object so that two angles, θ_{Rd} and θ_C, which are representing the directions of the radar and the target axes, respectively. The angles are measured with respect to a reference axis, which is assumed to be on the right hand side of the tracker. The controllers use these two position angles as inputs from the radar to generate a control signal, which is amplified by the amplifier before it is applied to the motor, in order to track the moving object. Besides tracking control, the controllers are also used to control the power matching between the PV array and the tracking system.

III. Photovoltaic Array SOURCE

A general block diagram of the PVA model for GUI environment of Simulink is given in Fig. 2. The block in Fig. 2 contains the sub models that are connected to build the final model. The number of series connected PV cells (Ns), the number of the parallel connected branches (Np), variable temperature (Tx), and variable solar irradiation level (Sx) are the inputs to the PVA model. The current of the PVA, which is the total load current, is also used as input to the PVA model to generate the voltage Vpv as the PV array output voltage by simulating the voltage equation of a PV cell as given by (1).

$$V_C = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_0 - I_C}{I_0}\right) - R_S I_C \qquad (1)$$

Where the symbols are defined as follows:
e: electron charge (1.602×10^{-19} C).
k: Boltzmann constant (1.38×10^{-23} J/°K).
I_c: cell output current, A.
I_{ph}: photocurrent, function of irradiation level and junction temperature (5 A).
I_0: reverse saturation current of diode (0.0002 A).
R_s: series resistance of cell (0.001 Ω).
T_c: reference cell operating temperature (20 °C).
V_c: cell output voltage, V.

The effects of the temperature and solar irradiation levels are represented by two variables gains. They can be changed by dragging the slider gain adjustments of the related blocks. The modeling of the PV array for Matlab/Simulink GUI environment is discussed in [1, 4]. Therefore it is not going to be discussed here again.

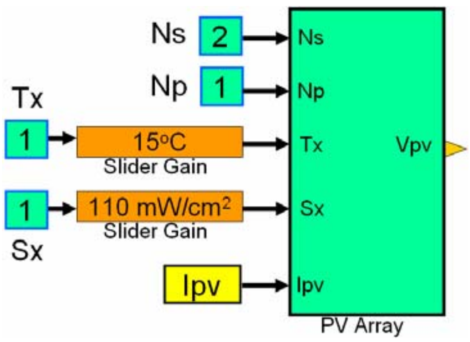

Figure 2. PVA Functional Block Model

IV. TRACKING SYSTEM

The principle diagram of the system to be studied is shown in Fig. 1. The system consists of a radar receiver, an amplifier, and a permanent magnet direct current (PMDC) motor driven tracking system. The motor and the radar are coupled together over a gear system. The radar is supposed to detect the position of the moving object and measure the position angle θ_C with respect to the axial reference position represented by reference axis as shown in Fig. 3.

The angles θ_{Rd} and θ_C shown in Fig. 3 represent the directions of the radar and the object axes, respectively, and are determined by the radar system. The controller uses these two inputs from the radar to generate a control signal, which is amplified by the amplifier before it is applied to the motor, in order to track the moving object. The difference between the car position axis and the radar axis is defined as the angular tracking error signal to be compensated, and is defined as:

$$e(t) = \theta_C(t) - \theta_{Rd}(t) \qquad (1)$$

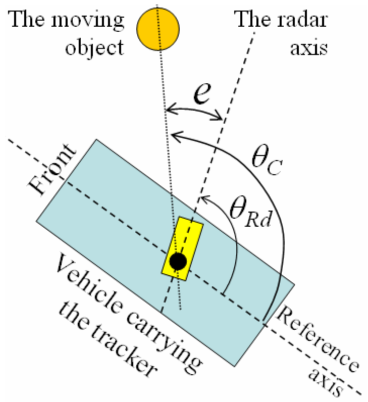

Figure 3. The schematic diagram of the tracking system.

As long as the error signal e(t) is not zero, then, the amplified value V_a of the controlled signal u is applied to the motor. The motor accelerates until it catches the moving object. If the radar axis overlaps the car axis and they are synchronized, the error becomes zero. When this condition is satisfied, the changes in both angles must be equal to each other for a zero steady-state error operation.

$$\frac{d\theta_C}{dt} = \frac{d\theta_{Rd}}{dt} \quad \text{while} \quad \theta_C = \theta_{Rd} \qquad (2)$$

The angle θ_C representing the object's position is the reference input to the controller. It is assumed that the radar can be rotated between 0^o and 360^o. Therefore the reference angle is also varied from 0^o to 360^o. However, only half of this range is simulated. The control block diagram of the system studied is given in Fig. 4 where only the blocks of the system components are shown.

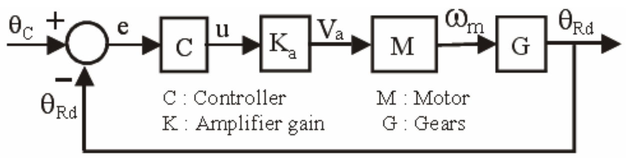

Figure 4. General block diagram of the Unified Motor-Control System.

Although a mathematical model of the system to be controlled is not needed in fuzzy logic based control systems; one is needed here since the system is to be simulated. In real time implementation a mathematical model of the systems may not be required, but it is for simulation. Therefore the simulation model of the tracking system comprising the power amplifier, PMDC motor, and the gears is obtained as shown in Fig. 5.

The radar tracking system modelled here is based upon a small prototype with a low inertia much smaller than the inertia of the PMDC motor itself. Therefore the radar mass along with the inertia are neglected. Since the motor is subject to drive only the radar body without any additional mass, the load is assumed to be constant without any disturbances. Therefore the main time constant of the system comes from the motor inertia and winding constants. Another time delay is introduced by FLC due to time required by the algorithm to process the fuzzy control rules. A radar system with a larger inertia would have made the system slower during transient periods. A system with slower time response gives an advantage to the controller for generating the required control actions. If a radar system with higher inertia and therefore higher time constant is used here, then the FLC would have more time to generate the required control actions. The selection of a faster system here forces the FLC to act for the worst cases.

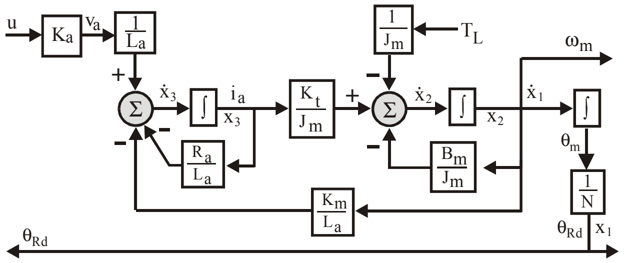
Figure 5. Simulation Diagram for PMDC Motor and gear system.

The amplifier in Figs. 4 and 5 is used to amplify the control signal to drive the PMDC motor. This Transistorized amplifier block is actually not necessary to be included in computer simulation model. However, it is required in real time application because the control signal from computer is not large enough to drive the motor. Therefore a power amplifier is needed. In order to have a more accurate model of the physical system, an amplifier block is also added in simulation model here. The gain of the amplifier is set to such a value that its output voltage never exceeds the nominal operating voltage of the PMDC motor for the highest input signal, which is limited with a normalized value by the FLC. Hence the saturation and overheating is prevented.

The variables x_1, x_2, and x_3 represent radar angle, θ_{Rd}, motor speed, ω_m, and motor current, i_a, respectively, in Fig. 5. A more detailed analysis of permanent magnet brushless dc motor can be found in [5].

V. THE FLC CONTROLLER

A fuzzy logic error driven tracking controller (FLC) is utilized to control the tracking system. Since the FLC generates the required control signal by compensating the error down to zero by implementing its fuzzy rules with a dynamical behaviour. The output fuzzy space used in this paper has 25 rules defined on two input spaces, which each one has five fuzzy subsets as Negative Big (NB), Negative Small (NS), Zero (ZZ), Positive Small (PS) and Positive Big (PB). The fuzzy rule table is given in Table 1.

An illustration of the fuzzy inference system from crisp inputs to fuzzy output is shown in Fig. 6. For any point (e(k), Δe(k)) on the trajectory plot of e(k) vs Δe(k), there are maximum two intercepting fuzzy sets on each one of the universes e(k) and Δe(k). Thus, for any sampling instant, the value of e(k) activates only one or two fuzzy sets in the universe of e. Similarly, the value of Δe(k) for the k^{th} sampling instant also activates only one or two fuzzy sets in the universe of Δe(k). For example, the point (e(k), Δe(k)) on the trajectory plot shown in Fig. 6 intercepts with the fuzzy sets ZZ and PS in the universe of e and with the fuzzy sets NS and ZZ in the universe of Δe. For the k^{th} sampling there are four active rules, which are used to obtain the final fuzzy output and then the final crisp control action by applying a defuzzification process. The FLC Simulink block model used in this work has been developed and described in [6]. Therefore it is not going to be repeated here.

Table 1. Modified fuzzy rule decision table.

		Δe				
		NB	NS	ZZ	PS	PB
e	PB	ZZ 1	PS 2	PS 3	PB 4	PB 5
	PS	NS 6	ZZ 7	PS 8	PS 9	PB 10
	ZZ	NS 11	NS 12	ZZ 13	PS 14	PS 15
	NS	NB 16	NS 17	NS 18	ZZ 19	PS 20
	NB	NB 21	NB 22	NS 23	NS 24	ZZ 25

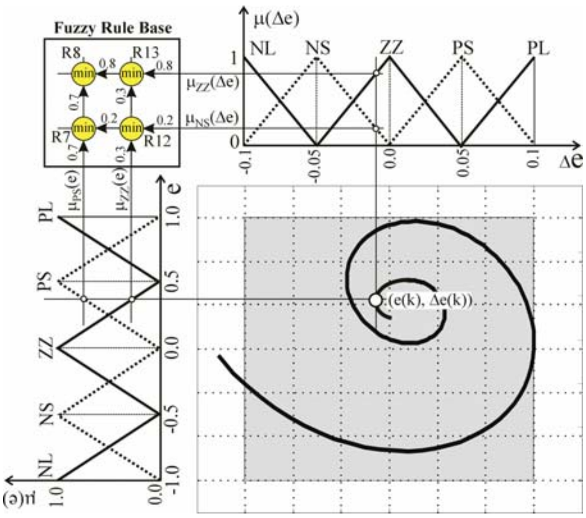

Figure 6. Fuzzy Logic Reasoning Rule Reasoning

VI. Digital SIMULATION

The unified Matlab/Simulink block diagram of the radar tracking system with the FL controller is given in Fig. 7. The simulation results of this system are shown in Fig. 8 for both FLC and PID controllers. In the tracking system, it is assumed that the radar is tracking moving objects so that after catching the object, the radar locks and tracks it on a surface with 360^o rotating ability. Therefore, the reference input to the radar tracking system is a ramp input as a function of the simulation time. It is also assumed that the moving object slows down and speeds up again during the simulation as shown in Fig. 8, where both FL and PID controllers are tracking the object. However, the FLC has a better and close tracking performance even if it has some small oscillations. In order to simulate the radar tracking system with the PID controller, the FLC block is replaced by a PID block with the parameters set to K_P=1.1, K_I=0.8, and K_D=0.

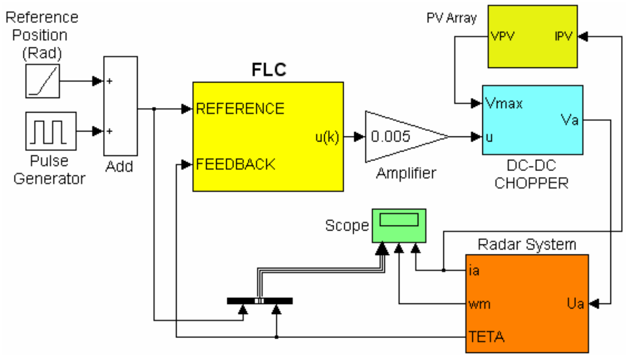

Figure 7. Fuzzy Logic FLC Control Scheme Using the PMDC motor for Radar Detection

The results given in this section are obtained by simulation using the system parameters given in Appendix. The time response of the moving target angle θ_C (reference) and radar angle θ_{Rd} (FLC and PI) are given in Fig. 8 where the overlapping of both angles are very clear showing a zero steady-state error operation. If any change occurs in the speed of the targeted object, the controller should perform necessary actions to keep on tracking with zero steady-state error. The effects of accelerating and decelerating speed on the controller performance are given in Fig. 8. The changes in solar irradiation level are included in the simulation as shown in Fig. 9 where the changes occur at 6^{th} and 10^{th} seconds. Since the controller handles these changes by controlling the DC chopper, the tracking is not affected by these changes.

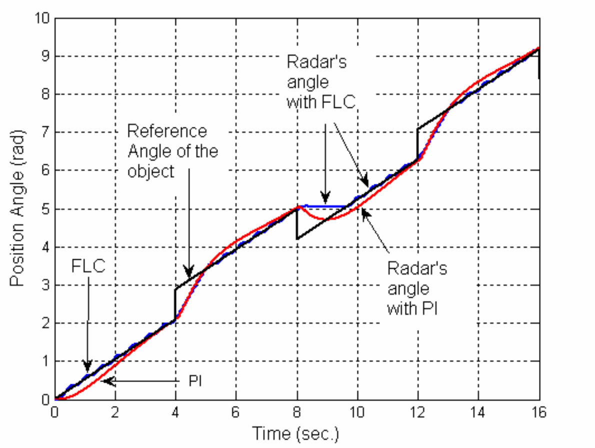

Figure 8. Radar tracking performances of both FL and PID controllers.

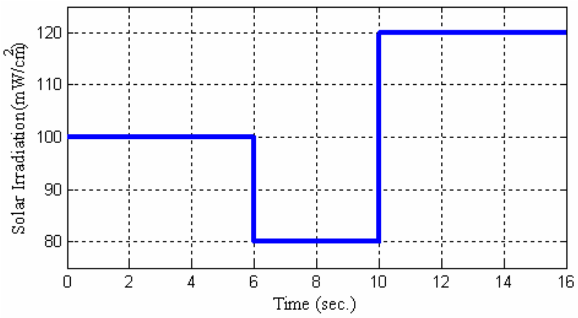

Figure. 9. Step changes in PV-Solar irradiation level.

The time variation of the controlled output u is given in Fig. 10. This is the signal that is amplified and applied to the motor. After the transient period, it settles dawn on a steady-state value. If the target were constant, the steady-state value of the controlled signal would have been zero. Since the target is moving with a constant speed, u has a constant non-zero steady-state value. The value of the controlled signal u increases or decreases for accelerating or decelerating target objects, and remain constant when the steady-state error is zero.

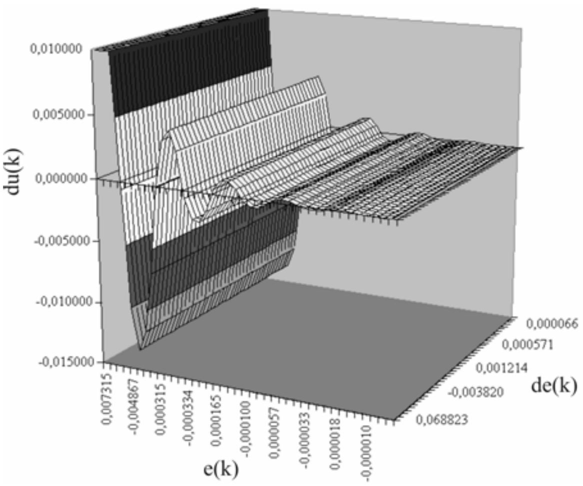

Fig. 10. Hyper Plane of the output signal Δu versus error inputs e and Δe.

VII. CONCLUSION

A low cost PV solar powered control scheme for tracking moving objects is presented and fully validated in this paper. All sub models are represented in the Matlab/Simulink Software environment. A fuzzy logic based tracking controller is used to control the PMDC Motor for effective moving object tracking under sudden changes in solar irradiation and/or operating temperature. The moving target traced here is assumed to be a motor vehicle, which moves on a leveled surface in the forward or backward directions. The problem can be expanded to track other objects capable of moving up and down as well. In this case a second tracking control loop in the added direction must be used to give another coordinate tracking axis to the radar system. Since the rule generation process here depends on the sign of e as long as e is not zero, and depends on the sign of Δe when e is zero, it becomes possible to determine the active rules to be used at each sampling instant instead of using all the rules. This process results in a considerable time reduction when running the FLC algorithm.

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APPENDIX

PMDC motor parameters:

R_a= resistance of armature winding =1.4 Ohm
L_a= inductance of armature winding = 0.0805 H
K_m= voltage constant = 0.095 V/rad
K_t = torque constant = 0.095 Nm/A.
J_m= moment of inertia = 0.0007432 kgm^2,
B_m= viscous constant = 0.000431 Vs/rad.
V_a= Nominal armature voltage =36 V
N= Turns ratio of the gears = 2.67