Wind disturbance elimination on dual axis solar tracker using fuzzy logic control

M Ikhwan¹, S Rizal¹,², M Ramli³,⁶, Z A Muchlisin¹,⁴ and M Mardlijah⁵
¹Graduate School of Mathematics and Applied Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
²Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
³Department of Mathematics, Faculty of Mathematics and Natural Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
⁴Department of Aquacultures, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
⁵Department of Mathematics, Faculty of Mathematics, Computing and Data Science, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia.

E-mail: marwan.math@unsyiah.ac.id

Abstract. The use of solar energy using solar panels began to be encouraged. Solar panels utilize solar radiation and convert it into clean and renewable energy. The problems of the accuracy of the panel facing right towards radiation are a challenge in the development of a driving system. Solar panels have limited motion, which is a maximum of phi, so that wind disturbances are very dangerous for motor drives and solar panels. This paper aims to eliminate wind disturbances in solar panel drive systems. The fuzzy logic control is used to determine the amount of power given to the driving motor to direct the panel towards solar radiation. Inputs and outputs of fuzzy controllers are arranged by dividing into each of the five members. Simulation results show that the position error of solar panels without wind disturbances reaches 0.3325° in zonal and 0.5210° in meridional. By using wind disturbances, this system managed to maintain errors smaller than 0.4285° in zonal and 0.6116° in meridional. After modifying the rule base and membership function, systems show decreasing of error half of recent trial.

1. Introduction

Renewable energy derived from solar radiation can be harvested with the help of solar panels. Solar panels are generally placed face up and slightly tilted to anticipate inundation of rainwater or dew. In fact, solar panels can produce electricity optimally if the panel continues to face the sun. Direct current (DC) motor technology is added to solar panel devices to improve panel mobility [1]. With a position modification, the efficiency of energy absorption can increase up to 30% compared to static panel [2].

Research on the direction and position of solar panels has used one and two driving motors. The solar panel one drive motor can direct the pitch angle of the panel in the direction of the sun altitude [3]. This type of drive is very likely to be done in the equatorial region, considering that the sun’s pitch angle does not change very much throughout the year. Controllers that have been developed for one
driving motor are classic control systems such as proportional-integral-derivative (PID) control and those that have implemented robust controls such as fuzzy, type 2 fuzzy, sliding mode, and firefly algorithm [4][5]. The previously developed robust development has also been tested on an inverted pendulum and obtained excellent results [6].

In contrast to one drive, a panel with two driving motors considers altitude and azimuth angles as reference controls [7]. Control with two driving motors can be used in any hemisphere because there are pitch and yaw angles that can direct right to the corner of the sun. It directs not only solar panels at altitude and azimuth angles but also uses solar radiation flux to lead to the most massive flux [8].

This paper aims to develop a fuzzy logic control (FLC) system for two solar panel drive motors. Previous research has used a stepper motor as a driver [9]. The disadvantage of a stepper motor is discrete control and must follow the breaker limit on the motor, but the advantage is resistance to disturbance. This study uses two DC motors that can be controlled continuously, and wind disturbances are eliminated by using a fuzzy set that describes the derivative of error.

2. Materials and Methods
The simulation was carried out at the coordinates of 5° 36 '16.3" and 95° 20' 47.5" with a comparison between uninterrupted and with disturbances. The first case uses FLC with linear rules, while the second case uses consideration of error changes and additional rules. This study uses a DC motor system described by the input voltage \( E(t) \), electric current \( i(t) \), and angular velocity \( \omega(t) \) in the following differential equations [1]:

\[
\frac{di(t)}{dt} = \frac{1}{L}(E(t) - Ri(t) - K_b \omega(t)) \tag{1}
\]
\[
\frac{d\omega(t)}{dt} = \frac{1}{J}(K_m i(t) - B \omega(t)) \tag{2}
\]

where the parameters used can be seen in Table 1.

| Parameter             | Symbol | Value          |
|-----------------------|--------|----------------|
| Resistance            | R      | 18.2214 \( \Omega \) |
| Inductance            | L      | 0.000866 Henry |
| Torque of e.m.f       | \( K_b \) | 0.030941093 V/(rad/s) |
| Torque of back e.m.f  | \( K_m \) | 0.030941093 N m/Ampere |
| Moment of inertia     | J      | 0.00009 Kg m\(^2\) |
| Friction viscous      | B      | 0.000025 N m s |

Angle error is obtained from the angle of altitude and azimuth on June 21, 2019. Altitude and azimuth angles are calculated using a series of physical formulas related to sample coordinates such as local hour angle \( \omega \), declination angle \( \delta \), latitude \( \phi \), and longitude of the observation position [11]. Altitude \( \theta_s \) and azimuth \( \gamma_s \) follow the following formula [12]:

\[
\theta_s = \sin^{-1} (\cos(\delta) \cos(\phi) \cos(\omega) + \sin(\phi) \sin(\delta)) \tag{3}
\]
\[
\gamma_s = \cos^{-1} \left( \frac{\sin(\delta) \cos(\phi) - \cos(\delta) \sin(\phi) \sin(\omega)}{\cos(\theta_s)} \right) \tag{4}
\]
\[
\gamma_s = \begin{cases} 
\gamma_c, & \omega \leq 0 \\
(2\pi - \gamma_c), & \omega > 0 
\end{cases}
\]
The degree of membership from the FLC input is the difference from the angle of altitude with the driving motor pitch or the azimuth angle with the driving motor yaw. Both types of errors are classified as the input set as follows in Figure 1. Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) are the division of fuzzy set areas equally in the domain. Angle error is translated as fuzzy membership degree or called fuzzification. The degree of membership obtained becomes input for the fuzzy voltage output set.

Like input, the output is also shared equally in domains called fast counterclockwise (CCWF), slow counterclockwise (CCWS), stop (S), slow clockwise (CWS), and fast clockwise (CWF). Both fuzzy sets can relate to each other using linear rules. The rule bases are described as follow [13]:

rule r₁: if error is NB then voltage is CCWF
rule r₂: if error is NS then voltage is CCWS
rule r₃: if error is Z then voltage is S
rule r₄: if error is PS then voltage is CWS
rule r₅: if error is PB then voltage is CWF

The center of area (CoA) is a method for determining the value of control based on the value of the output set area with a membership value greater than zero. The average weight of a region limited by the membership function is calculated to be the most exact value of some fuzzy values. This value becomes the input for the motor with the calculation formula as follows [14]:

\[ u^{CoA} = \frac{\Sigma_u u \mu(u)}{\Sigma \mu(u)} \]  

(5)

where \( u^{CoA} \) is defuzzification result, \( u \) is error input, \( \mu \) is membership degree of error input, and \( U \) is the set of fuzzy membership function that resulted \( \mu > 0 \).
Elimination of position changes is caused by wind using derivative functions. Previously the membership function in Figure 1 and Figure 2 was only able to illustrate that the voltage given was following the angle error. In controlling wind disturbances, there is an additional fuzzy membership function by considering the degree of change in angle. This change of angle is divided into five membership sets as follows:

![Membership Function Diagram]

**Figure 3.** Rate of angle change as FLC input

The addition of fuzzy sets causes changes in the way the calculation of the value of the membership degree is calculated for the FLC output. There are two grades of membership degrees at the input, but only one set of degrees of membership can be translated as output. The membership degree used is to follow the following formula [15]:

\[
\alpha_r = \min_{i=1,...,n} \{ \mu_i(u_i) \}
\]  \hspace{1cm} (6)

where \( \alpha_r \) is membership degree of FLC output, \( \mu_i \) is membership degree of each FLC input, and \( u_i \) is input vector for error and delta error angle.

The linear rule base cannot be used anymore because the second input of the FLC must be included in the rule. Rule modification with “and” relations can be seen in Table 2 [16].

| \( \Delta e \) | e | NB | NS | Z | PS | PB |
|----------------|----|----|----|----|----|----|
| NB             | CCWF | CCWF | CCWS | CCWS | S |
| NS             | CCWF | CCWS | CCWS | S | CWS |
| Z              | CCWS | CCWS | S | CWS | CWS |
| PS             | CCWS | S | CWS | CWS | CWF |
| PB             | S | CWS | CWS | CWF |

### 3. Results and Discussion

The simulation was carried out for 600 minutes with a location that directly affected the wind. Solar panels already have enough breakers to maintain the position, but the effects of powerful winds can change the position of the solar panel.

The initial simulation is done by setting the altitude and azimuth angles without wind disturbances. The fuzzy controller used is the fuzzy set in Figure 1 as the input and Figure 2 as the output. Both fuzzy sets are related to the linear rule base. The simulation results on the altitude and the azimuth can be seen in Figure 4.

Figure 4(a) shows that the fuzzy controller can adjust the position of the driving pitch right at the angle of altitude. Pitch experienced a large oscillation at the start of the simulation caused by an error
that was first obtained very large at 20°. The fuzzy controller instructs the motor to provide an enormous voltage value so that overshoot occurs at 19°. In general, the controller managed to direct the pitch angle to follow the altitude with an accuracy of mean absolute error (MAE) 0.3325°. Similar to the pitch angle, the yaw angle controller (Figure 4(b)) also experience large oscillations at the start of the simulation. The initial error that must be controlled is 65° so that the driving motor drives at maximum power. The resulting overshoot is quite significant, the value reaches 50°. After overcoming the oscillation in a few minutes, the control system has been able to direct the yaw angle right in the azimuth angle. Errors formed from the azimuth and yaw angles are measured by the mean absolute error of 0.5210°. MAE value is higher than pitch control, the cause suspected of contributing to the magnitude of the error value is a relatively large initial error value and the length of the oscillation at the beginning of the simulation.

The control system successfully controls the pitch and yaw angles following the altitude and azimuth angles. But it still leaves a small oscillation work along the reference angle. The elimination of the influence of the wind on the control angle of the motor can be affected by this small oscillation. It is evidenced by the increase in the size of the error during the simulation using wind disturbances. The simulations show that mean absolute error increases to 0.4285° at the altitude angle and 0.6116° at the azimuth angle (full simulation figures are not displayed, but wind disturbances are explained in Figures 5 and 6). Therefore the addition of a fuzzy set and a new rule base are needed to produce perfect control and can eliminate wind disturbances. Next, the simulation is done by using the fuzzy set in Figure 1 and Figure 3 as the fuzzy input and set in Figure 3 as the output. The Rule base is modified using the "and" relation in Table 2.

Figure 5 shows that the oscillation in the first control (blue) has not been seen in the modification of FLC (red). The effect of small oscillations on wind recovery has been eliminated. FLC modification can restore the position of the pitch motor to the reference angle in just 1.2 seconds. After experiencing wind disturbances, the modification control system was able to reduce the error value by half of the initial error value. Overall, the mean absolute error value in controlling the pitch angle is 0.2068°.
There are no much different from the pitch angle, controlling the yaw angle managed to reduce the mean absolute error to $0.2736^\circ$. In Figure 6, it can be seen that the modification of FLC also succeeded in eliminating small oscillations that had previously appeared on the initial controller. The elimination of wind disturbances at the yaw angle has been successfully carried out by the new controller. The duration of recovery of the disturbance also reaches 1.2 seconds. Even though the azimuth and yaw are at an angle below $0^\circ$, FLC still works to control the motor yaw angle. It is caused by the formation of symmetrical fuzzy sets on the negative and positive angles. The "and" relations in Table 2 are also formed on the same rotation between clockwise and counterclockwise.

The modified FLC on the angle control of a solar panel motor is greatly affected by disturbance. Figure 5 and 6 show that wind is given in the time range $13.5 \leq t \leq 14.3$ at two different angles, and the solar panel can return to the reference angle. For wind disturbance, modification using derivatives can reduce errors and shorten recovery time. In general, there is still one period of oscillation that escapes control, but rapid recovery is one of the notable findings in controlling the driving angle of solar panels.

4. Conclusions
The FLC controller can direct the solar panel directly to the sun. In the first control, the FLC has managed to control the pitch and yaw angles following the reference angle, but there is a significant oscillation at the beginning of the simulation and small oscillations along with the simulation. The
measured error value is 0.3325° at the altitude angle and 0.5210° at the azimuth angle. The error value continues to increase with the influence of wind disturbances. The resulting error value increases to 0.4285° at the altitude angle and 0.6116° at the azimuth angle. The elimination of wind disturbances has gone well, but an increase in error values requires modification of the FLC. The modified FLC simulation results successfully reduce error values and eliminate wind disturbances. The last error value obtained is 0.2068° at the altitude angle and 0.2726° at the azimuth angle. The derivative modification not only eliminates wind disturbances but also reduces the error value of controlling the driving angle of the solar panel.

References
[1] Ikhwan M, Mardlijah, and Imron C 2018 Proceedings International Conference on Information and Communications Technology (ICOIAC) 784–788
[2] Katrandzhiev N T and Karnobatev N N 2018 Proceedings IEEE 27th International Scientific Conference Electronics 1–4
[3] Rani P, Singh O, and Pandey S 2018 Proceedings 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering 1–5
[4] Mardlijah and Zuhri Z 2018 TELKOMNIKA (Telecommunication Comput. Electron. Control) 16(6) 2988–2998
[5] Mardlijah, Zhai G, Adzkiya D, Mardianto L, and Ikhwan 2019 Syst. Sci. Control Eng. 7(1) 189–197
[6] Mardlijah, Jazidie A, Santoso A, and Widodo B 2013 Int. Rev. Autom. Control 6(4) 431–440
[7] Abadi I, Musyafa A, and Soepriyanto A 2015 Int. Rev. Electr. Eng. 10(3) 390–398
[8] Sawant A 2018 Proceedings 2nd Int. Conf. I-SMAC (IoT Soc. Mobile, Anal. Cloud) 454–459
[9] Hawibowo S, Ala I, Citra Lestari R B, and Saputri F R 2018 Proceedings 4th International Conference on Science and Technology 1–4
[10] Mardlijah, Rinanto N, and Soemarsono A R 2017 J. Theor. Appl. Inf. Technol. 95(20) 5562–5570
[11] Sproul A B 2007 Renew. Energy 32(7) 1187–1205
[12] Braun J E and Mitchell J C 1983 Sol. Energy 31(5) 439–444
[13] Mardlijah, Jazidie A, Widodo B, and Santoso A 2103 J. Theor. Appl. Inf. Technol. 47(2) 824–831
[14] Sousa J M C and Kaymak U 2002 Fuzzy decision making in modeling and control World (Scientific Publishing Singapore)
[15] Hans-Jürgen Zimmermann 1996 Fuzzy Set Theory - and Its Applications, 3rd ed. (Kluwer Academic Publishers Boston Dordrecht London)
[16] Abadi I, Musyafa A, and Soepriyanto A 2015 Int. Rev. Model. Simulations 8(6) 640–652

Acknowledgments
Authors would like to express gratitude to the Universitas Syiah Kuala for financial assistance in term ‘Program Riset Unggulan Unsyiah Percepatan Doktor’ with contract number 292/UN11.2/PP/PNBP/SP3/2019. We also thank you to all those who supported this research.