Unmanned Aerial Vehicle (UAV) Predictive Control Energy Management Model

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ABSTRACT

Limited battery capacity is a problem that needs to be overcome because the battery is the Unmanned Aerial Vehicle's energy source. Optimization is carried out based on battery usage patterns. Predictive model method in managing energy usage [1], even though there are additional energy sources such as solar cells. This system is known as a hybrid energy source. Energy consumption patterns shoul be analyzed before applying algorithmic prediction models. Creating a precise energy consumption prediction model is an important topic. A general consensus regarding energy consumption models has not been reached at this time, so there are many variations in models and their complexity. This research applies a battery management system by considering several UAV performance parameters. Parameters that are considered to significantly influence performance and energy consumption are altitude and speed. The higher and faster a vehicle goes without maintenance, the more energy it uses. Energy availability is the main problem in order for the system to work sustainably. Based on the simulation modeling, a correlation was obtained between the type of UAV movement and the regulation of energy use. This correlation can also be realized mathematically. Then it can also be interpreted physically as to what the drone should do with the existing battery availability configuration.

CCS CONCEPTS

• **Engineering and Software Development**;; • **Computer and Software Engineering**;;

KEYWORDS

Predictive model, energy, Unmanned Aerial Vehicle

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1 INTRODUCTION

UAVs in the form of drones or fixed wings are currently being rapidly developed and implemented. An unmanned aerial vehicle (UAV) uses batteries as an energy source. The limitation of the battery is its relatively short lifespan. This is a problem to which a solution will be sought. This problem raises a research question.The first question is how to extend the duration of battery usage; the second question is what method to use for optimization.Many studies direct the topic to methods of minimizing UAV power consumption. Mahmood et al. proposed using not only batteries as a power supply but also additional fuel cells and super capacitors. Mohsan et al.considered aspects of the battery charging method. Wang et al. concerned about the effect of altitude as an example case of a trade-off between energy and flight altitude. Generally, the assumption of linearity is made for simplification so that a model can be made because many factors affect UAV performance. Cheng at al.promoted the non-linearity of battery usage conditions. The disturbance cannot be ignored in aviation, so other relatively important parameters must be considered. Stolaroff et al.and Choi et al.considered more input parameters, such as the UAV payload.and varying speeds , in addition to the lift-to-drag ratio.

Commonly done is to use additional energy sources, such as solar cells. Such conditions are known as hybrid energy sources. The novelty of this research is the combination of the use of hybrid energy sources and energy management using predictive control energy methods. Before making predictions, the thing that must be considered is the existing model. A particular parameter for optimization has to be found out before creating a model. Because the object being optimized is battery usage on the UAV, the first thing that must be done at the beginning is to determine the parameters of the UAV. Parameters that are considered to have a significant effect on performance and energy consumption are altitude and speed. The initial assumption is that the nature of the changes that occur will be linear. The experiment was carried out by reviewing three vehicle conditions. The first is modeling the takeoff, then moving flat or sliding, and the next is landing. There are various ways to manage energy consumption, one of which is by creating a prediction-based control system [1]. This solution can involve hardware or software. The work pattern uses certain algorithms that are adapted to the supporting devices. This prediction-based energy control can be implemented in other systems that have energy limitations.This research is presented in several sections. The second section discusses literacy, which supports the development of this system. The third section discusses system development methods, followed by section four, which contains the results and analysis. Section five is the overall conclusion of this research..

2 LITERATURE REVIEW

2.1 Model Predictive Control (MPC)

Model Predictive Control (MPC) is one of the control methods that uses predictive conditions. The appearance of predictive control based on desire in the process of output in a system can then be known. A series of calculations in control will minimize the objective function, and any output of the previous system will be included in the calculation as output in the future or next in each series of calculations. Systematically, this model can be described in the block diagram in Figure 1

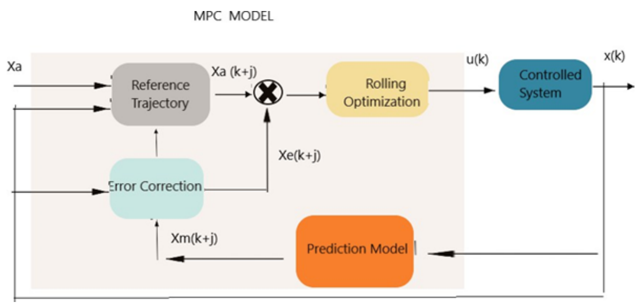

Figure 1: Block Diagram of Predictive Control Model [5]

The output of the future process is predicted at each sampling time using the process model. The output of the prediction process Xm (k+j) is influenced by past input and output values as well as the predictive control signal. The control signal is calculated by optimizing the previously defined criteria function in MPC model. The aim is to keep the process close to signal Xa as the input of the reference trajectory. The criterion function is a quadratic function of the error between the predicted output signal and the reference trajectory. Generally, control objectives are included in the criteria function.Some of the advantages of this MPC method are that the concept is very flexible, can handle multivariable systems, compensates for time delays, and has the ability to calculate measurable disturbances. Apart from having advantages, this method also has weaknesses, namely the reduction in signal control rules, so it requires a good process model. If it is not used properly, the control results will also be less than desired.The method is divided into three parts: the control signal u(k), the output x(k) and the limit N, which determines the next output. The working principle is to use a system model as a prediction of future output within a range of the limit. The control signal is calculated to minimize the predetermined objective function so that the process output signal is in accordance with the system characteristics. The next output signal follows the calculation using the previous control signal. This can be explained in Figure 2

Based on this graph, a mathematical correlation can be created that has a physical meaning for the system control mechanism. Transfer function or space state and cost function are two things that generally affect system performance in predictive control models. The transfer function of the actuator in the form of a DC motor is a comparison between the angular speed and the tangential speed. Physically, this is illustrated by a comparison of mechanical parameters with electrical parameters. In calculating the transfer function,

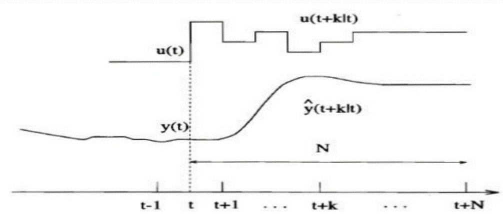

Figure 2: MPC Strategy [6]

reduction or disturbance factors are taken into account in addition to the parameters that change the form of energy use. Meanwhile the cost function is a formula or equation reflecting the change in error against references and control actions. This predictive control method can work in linear or non-linear domains. Linear methods are simpler, and manipulations and assumptions are made to make them easier to model. If a system works in continuous time mode, adjustments will be made because, basically, the law of the predictive model is that it works in discrete mode.The sampling process will be carried out as an adjustment mechanism, preferably at a relatively high speed. This adjustment process can be done by reviewing the rising or settling conditions. The predictive model in the discrete space model considers state predictions, and the control action is optimization with certain limits using a cost function with a constant weight matrix. At each sampling, the problem that occurs is linear control optimization, also known as linear time invariance (LTI) [2]. The general mathematical formulation of the LTI is shown in equation 1 and 2

$$x\,(k+1) = Ax\,(k) + Bu\,(k) \tag{1}$$

$$y\,(k) = Cx\,(k) \tag{2}$$

where x ∈ Rn is the state vector, u ∈ Rn is the controlled input vector, y ∈ Rn is the output vector, A ∈ Rn×n is the state matrix, B ∈ Rn×nu stands for the input matrix, C ∈ Rn×n is the output matrix, and k ∈ N denotes the sampling instant number [2]. D'Andrea's energy consumption model is based on the drone's lift-to-drag ratio. The formula is optimized for stable drone flight and utilizes the drone's mass, airspeed, lift-to-drag ratio, and battery power transfer efficiency. This model consists of two variations. The standard variations do not relate to the wind, and the other variations that relate to the wind relate to the headwind. This model goes further by applying the conditions when the drone unloads its payload before resuming its flight.

The model makes several assumptions to model its energy consumption. Lift-to-drag ratio with a constant value selected, inspired by helicopter lift-to- drag ratio, and used as a comparison around it. Variables such as cruising speed during missions are set to predefined values. The power transfer efficiency is also set to a value. The Dorling is another energy model. This model is not detail as D'Andreas, it only takes into consideration drone hovering. However, this model consider the components used in the drone such as the number of rotors and propeller area.

2.2 Battery Management System

Battery management systems (BMS) involve various technologies, such as microcomputer technology and detection technology. In this system, the detection technology applied is dynamic [4], [6]. The operating status of battery cells and battery packs is detected accurately, as is the remaining battery capacity. The systematics of this system are shown in the block diagram in Figure 3.

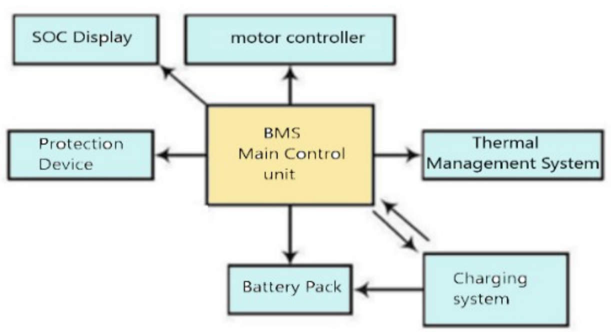

Figure 3: Battery Management Systems

The battery management system structure adopts a modular and distributed design. The system includes a two-level control structure, namely a local measurement module and a central processing module. The central dispatch module communicates with the microcontroller and the local measurement module. The main function of the local measurement module is data acquisition, especially temperature, current, and voltage data acquisition, charge and discharge control, and power measurement. The data acquisition module in the battery management system is responsible for collecting various battery status parameters, such as current, voltage, and temperature. The charging control module performs automatic charging according to the three pre-charge stages, constant current charging, and constant voltage charging, and according to the collected data. The charging and discharging processes are controlled by the balancing module so that the battery is more stable and consistent.

2.3 Hybrid Energy Sources in Unmanned Aerial Vehicle

Hybrid energy sources are built from a combination of two or more different systems. This system serves to minimize the deficiencies that exist in a system by combining it with other systems. The purpose of this system is to improve the performance of the energy source. Solar cells can be used as an alternative energy source when combined with batteries, the aim of which is to increase the flight time and distance that this aircraft can cover. Solar cells were chosen as a source of electricity combined with batteries due to weather and climate factors that support Indonesia's territory. Figure 4 illustrates the physical construction of a hybrid energy source between solar cells and batteries.

Meanwhile, from the bottom perspective, it looks like the motor speed controller. It also shows the working pattern of solar cells and batteries as energy sources for the motor as an actuator. Figure 5 illustrates how the sun collects the energy in a solar cell, which converts it into electricity.

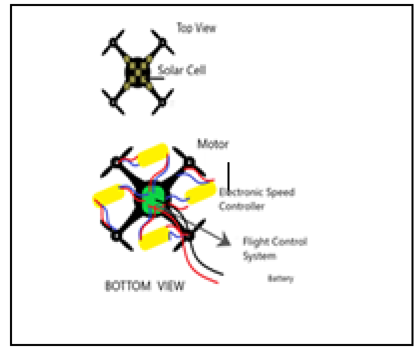

Figure 4: Hybrid Energy Sources in UAV

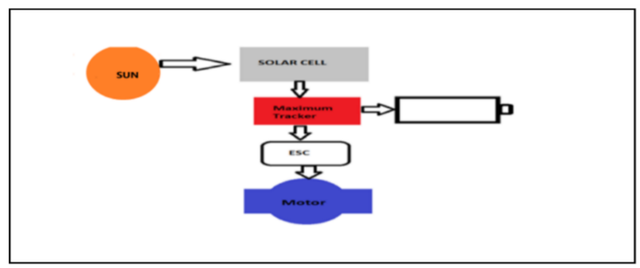

Figure 5: Hybrid energy source work pattern

The maximum tracking section monitors the maximum power. In flat flight, power is used directly from the solar cell to the motor. While gliding, the motor does not require too much power, and the battery begins to charge. If more power is needed when the vehicle is boarding or when the sun's intensity is low, the battery supplies the required power. There is an electronic speed control (ESC) that regulates the speed of the motor connected to the maximum tracker. Equation 3 describes motor transfer function math formulation

$$Gm = \frac{\omega}{V} \tag{3}$$

Where Gm is the transfer function, w re represents angular velocity, and V is tangent velocity. The use of motors is adjusted to the type of UAV because the performance and characteristics will be different for each UAV movement.

3 PROPOSED METHOD

This research is linked to an energy management algorithm with a hybrid energy system between solar panels and batteries. The solar panels are directed when the drone moves horizontally, while the battery is used for climbing movements. Predictive control algorithms work in this system, which pays attention to previous conditions to predict energy availability. Previous condition information will be stored in a past condition memory system. This information will be used to estimate battery availability. Therefore, knowing the current position of the drone and how it will move next becomes important to support the performance of this predictive algorithm. Figure 6 explains the drone control scheme for altitude parameters.

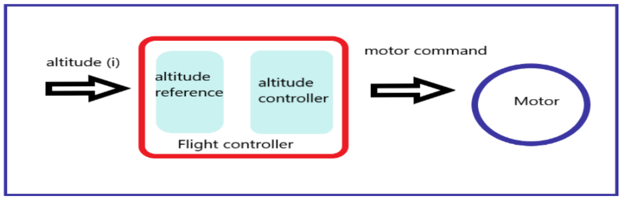

Figure 6: Drone Control Scheme

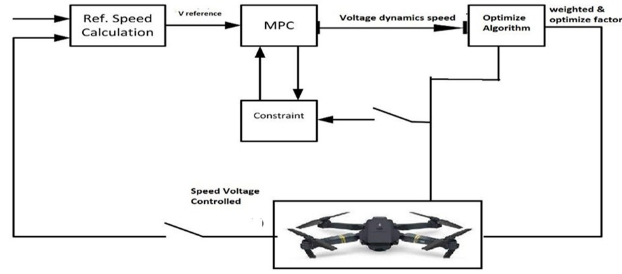

Figure 7: System Design

The important part that determines this drone is the motor movement. The parameters are speed and direction of rotation. Speed is also considered tangentially or angularly because it will have different effects. Something that is closely related to the rotor is the availability of energy, so there are many ways to achieve this condition. The use of hybrid energy sources and selecting energy management algorithms to be efficient are some of the efforts made regarding the availability of energy. Using hybrid energy sources requires a good energy management strategy [8]. In this research, the optimization algorithm used is MPC. MPC has been widely used in industrial control processes because of the robustness of its algorithms[9]. The main advantage of MPC is that there is a trade-off between computational load and corrections that occur smoothly. This is suitable for nonlinear or uncertain dynamic systems. The energy consumption modeling used here is an approach to motor usage parameters on drones. During certain drone movements, the motor will move at a particular speed. UAV energy consumption consists of two main parts, namely motion system and communication system. Next is the consumption of propulsion energy to ensure the UAV remains flying high and supports its movement. Propulsion energy consumption is determined by flight status and is usually much more significant than communication-related power expenditures. In UAVs, whether drones or fixed wings, flying activities are a complex geometric phenomenon with relatively difficult control. Many parameters or variable components are involved. [10]

3.1 Model

Modeling is a mechanism to describe a system, with various parameters and variables that affect performance. The modeling here is directed at a hybrid energy source between solar cells and batteries. Prediction-based modeling, taking into account the process model of the hybrid energy source system. In the initial conditions before modeling, initial experiments were carried out to see the correlation between the parameters and the performance of the drone as a kind of UAV. Based on the data and information, a physical and mathematical approach will be made. Then by using a certain algorithm that supports MPC an optimization model will be made [2]. Validation will be carried out to determine the extent of optimization obtained by the modeling. MPC allows mitigating constraints and predicting the future by paying attention to inputs in current conditions. The MPC here is proposed to control the autonomous control of the drone.

In the design model, Figure 7 shows the flow of correlation between UAV speed regulation and the energy used [3].

In the process model later this will be detailed regarding the use of batteries and solar cells. Based on the previous input in the form of using a voltage with a certain speed, the output will be predicted and after that optimization efforts. The model proposed in this research is a review of motor movements during horizontal and vertical UAV movements. Motors are an important part of a drone's motion system. Performance improvement assessments can be viewed based on the condition of energy availability or models of energy use patterns. In this research, performance assessment is based on energy use patterns in the motor with the assumption that there are no external conditions. This perspective is closer to the energy consumption model proposed by Dorling.

3.2 Sliding Mode

In this mode, the important thing is to control the movement path from the current condition to the next condition according to the condition left behind. The condition of sliding or moving with a horizontal trajectory means that every point of movement is controlled continuously on a sliding surface. This symptom can be stated mathematically: a straight line path will occur if it descends from a flat surface with a value of zero. If horizontal movement is allocated power from the solar panel, The amount of energy that can be used by the rotor can be estimated by calculating the conversion of solar panel power into electrical power, and then a DC-to-DC conversion mechanism occurs so that the resulting voltage is more stable. The calculation of the conversion of solar cell power and electrical power can use equation 4.

$$V = Voc.\ Ns - -Kv.T \tag{4}$$

V is the voltage produced, Voc is the voltage when open circuit, while Kv is the heat constant and TC is the working temperature. The stability of the voltage must be maintained so that a DC-to-DC converter is used. This type of converter is considered to have good performance if it has small losses.

4 RESULTS AND DISCUSSION

4.1 DRONE and Energy

Simulation using Proteus Parameter Setting

Battery	1 (one) Li On 3.7 Volt
Solar Panel	PV array
Converter	Buck Boost Motor : 5 V, 1 A

4.2 Experiment Scenario :

4.2.1 *In the condition of the UAV vertical motion.*

UAV uses battery that is integrated with a solar panel. Figure 8 illustrates this condition.

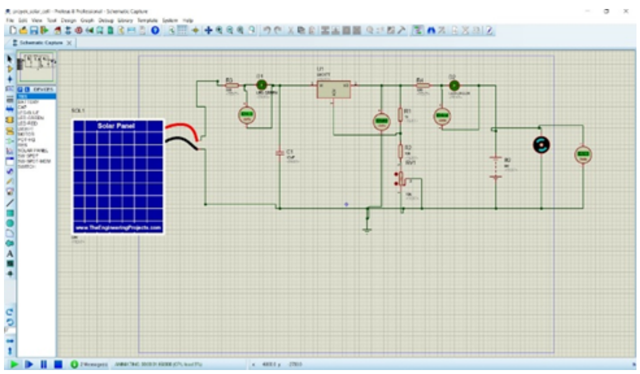

Figure 8: UAV uses Battery and Solar Panel

Table 1: Battery Charging by Solar Panels

No	Time (minute)	Voltage
1	5	2.8 V
2	10	2.6 V
3	15	3.2 V
4	20	3.5 V

At this time the battery uses a relatively large capacity so that the influence of the solar panel is not too significant on battery charging.

4.2.2 *UAV sliding motion/ horizontal movement.*

The UAV uses energy obtained from solar panels only.Figure 9 shows this situation.

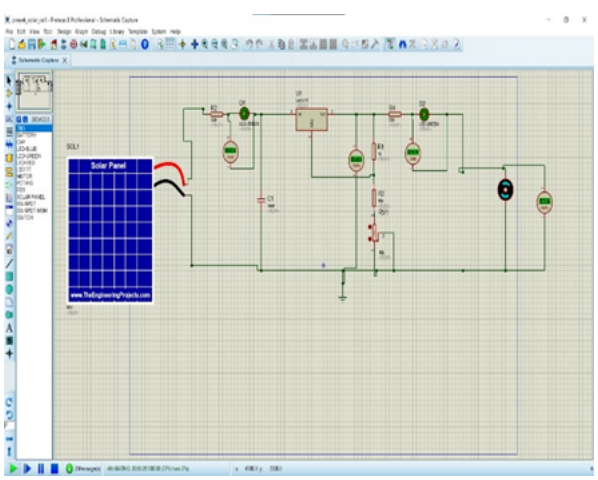

Figure 9: UAV uses solar panel

Table 2: Solar Panels Voltage

No	Time (minute)	Voltage
1	5	2.2 V
2	10	2.4 V
3	15	2.2 V
4	20	V

4.2.3 *UAV in sliding motion.*

The UAV uses energy obtained from solar panels and battery. Figure 10 illustrates this condition.

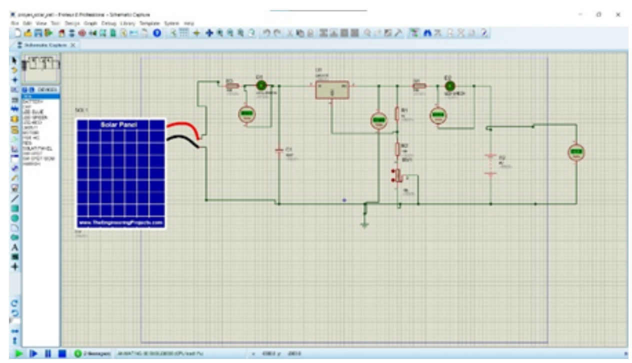

Figure 10: UAV uses Battery and Solar Panel

Table 3: Battery Charging by Solar Panels

No	Time (minute)	Voltage
1	5	3.6 V
2	10	3.2 V
3	15	3.4 V
4	20	3.6 V

There are just a few changes to the battery with this energy usage setting. The voltage used by the UAV is the result of the superposition of solar panel energy with battery energy. But the value is not significant if the battery state of charge is low.

Resume of the experiment

No	**UAV task**	**Energy management**	**Explanation**
1	Slide	Puav = Pbatt+ Psp	Uav is powered by battery and solar panel
		Pbatt= 0 Puav = Psp	Uav is powered mainly by solar panel
2	Climb	Puav= P batt + Psp	Uav is powered mainly by battery
		Puav= Psp	Emergency condition , because battery empty.

5 CONCLUSIONS AND RECOMMENDATIONS

Regulating the use of electrical energy on drones is important. In this study, arrangements were made for the use of batteries to be very effective and efficient. Based on the experiment, it appears that when the battery is only connected to the solar panel, the voltage stored in the battery is relatively small, and vice versa. When the battery is integrated with the drone, the settings are made. When there is a difference in altitude, the solar cells tend not to be activated to charge the battery. Batteries should be used for energy resource during takeoff and climb, while solar feeds UAV during level flight. It is the energy management system . The predictive algorithm will display energy usage estimates based on previously recorded conditions.

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REFERENCES

[1] D. William, " Distributed Model Predictive Control for More Electric Aircraft Subsystems Operating at Multiple Time Scales", IEEE transactions on control systems technology,vol 28, no 6, 2019
[2] C.S Christopher et.al,"Linear model predictive control for vision-based UAV pursuit", Journal of Unmanned Vehicle Systems , vol 8 , no 4, December 2020
[3] T.M Nsilulu *et al.* , " Model Predictive Control: A Survey of Dynamic Energy Management", In Proceedings of the 18th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2021), pages 123-129
[4] Dehua Shi et. al," Model Predictive Control for Nonlinear Energy Management of a Power Split Hybrid Electric Vehicle , Intelligent Automation And Soft Computing, 2020 Vol. 26, no. 1, 27–39 . 2022
[5] F. Sajjad et. al," Fast Model Predictive Control and its Application to Energy Management of Hybrid Electric Vehicles, Intechopen
[6] E. Camacho dan C. Bardons, "Model Predictive Control," Springer., 2006.
[7] David Sotelo *et al.*, "Model Predictive Control with a Relaxed Cost Function for Constrained Linear Systems', Hindawi Mathematical Problems in Engineering Volume 2020, Article ID 7485865, 10 pages https://doi.org/10.1155/2020/7485865.
[8] Tao Lei et.al," State of art on energy management strategy for hybrid-powered unmanned aerial vehicle", Chinese Journal of Aeronautics, Vol 32, no 6, pp : 1488–1503, 2019
[9] Max Schwenzer et.al, "Review on Model Predictive Control: An Engineering Perspective",The International Journal of Advanced Maufacturing Technology (2021) 117:1327–1349
[10] Peter Sarunic, Rob Evans," Hierarchical_model_predictive_control_of_UAVs_performing_multitarget-multisensor_tracking," IEEE TRANSACTIONS on Aerospace and Electronic systems vol. 50, NO. 3 July 2014