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***Research paper***

# Fuzzy Inference System for Throttle Control of Pedal-Assist Electric Bicycle

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**Abstract**

Electric bicycles have played an important role as an environment-friendly and healthy alternative for personal mobility. Pedal-assist bicycles, also known as electric-assist or power-assist bicycles, are one of the two kinds of electric bicycles that offer flexibility to the rider by allowing a combination of electric and human power for driving the bicycle. This study aims to develop a fuzzy inference system for controlling the throttle input of an electric bicycle intended to operate as pedal-assist. Bicycle acceleration and cadence angular acceleration are used as inputs to the fuzzy inference system, with the throttle control as output. Data are gathered based on several inputs and the performance of the control algorithm is analyzed.

***Keywords***: *fuzzy inference system, intelligence, mamdani, motor control, simulation, software qtfuzzylite,*

## 1. Introduction

Electric bicycles have played an important role as an environment-friendly and healthy alternative for personal mobility. This study focuses on pedal-assisted bicycles, also known as electric-assist or power-assist bicycles [1]. Pedal-assist bicycles offer flexibility to the rider by driving the electric bicycle using a combination of human power and electric power from the bicycle.

Researchers have implemented several control schemes for dynamic control of a pedal-assist bicycle. The study of Mallari, Macaraig, Navarrete, and Marfori [2] implemented a control algorithm for dynamic control of an electric bicycle using a power model. Their implementation computes for the intended maintaining speed of the rider and uses that speed to compute for the target power at which the bicycle should run. The target power is then controlled using proportional control.

The main weakness of the study of Mallari, Macaraig, Navarrete, and Marfori is that the power model used is based on characteristics of the electric bicycle, which needs to be determined for each rider. For example, for their algorithm to work, there is a need to update the rider weight for each rider, or if the rider is carrying a heavy load. Constants also dynamically change, like the coefficient of rolling resistance which decreases as tires are used. Therefore, there is a need to implement a more robust control scheme that are independent of the characteristics of the rider and electric bicycle.

This study aims to implement control of a pedal-assist bicycle using a fuzzy inference system that can control the throttle input of the motor controller independent of the characteristics of the rider and bicycle. This study also controls the electric bicycle without the need for human power input to eliminate the need for the torque sensor to reduce the cost of implementation.

Fuzzy Logic is a form of Boolean Logic where the truth tables varies in the between of 1 and 0 [3,4]. Fuzzy Logic depends on the degrees of truth [5]. This theory is not based on the traditional True or False [6,7,8]. For this research the Mamdani Fuzzy Inference System can be used [9, 10, 11, 12]. Matlab can be used to program the Fuzzy Logic System [13, 14, 15, 16, 17, 18].

## 2. Fuzzy Inference System Design

The theoretical design of the fuzzy inference system will be divided into four (4) parts. First is the definition of the inputs and their respective membership functions, second is the definition of the output and its respective functions, next is the definition of the configurations used and finally is the set of rules used in this study. There are instances where the Fuzzy Logic System will have incomplete information. In that case Rough Set Theory can be used [19,20,21]. Rough Set Theory presents a Mathematical Approach in Vagueness and uncertainty [22, 23].

### 2.1. Inputs

#### 2.1.1. Brake (brake)

The brake is a signal, either ‘1’ or ‘0’ where ‘1’ means the user is pressing the brake while ‘0’ means the brake is disabled. Fig. 1 shows the membership function for brake.

#### 2.1.2. Human Power Significance

This is a variable used to determine if the power exerted by the rider is theoretically providing driving the bicycle wheels. This is a value either ‘0’ for insignificant or ‘1’ for significant. Human Power is significant if cadence is greater than or equal to the angular speed of the wheels multiplied by the gear ratio. Fig. 2 shows the membership function for human power significance. Another method that can be used here is by using Neural Network with Spatial processing [24, 25, 26].

### 2.1.3. Bicycle Acceleration

Acceleration determines if the electric bicycle is slowing down, speeding up, or simply trying to maintain its speed. If the acceleration is negative it means the e-bike is slowing down, if it's positive, it means the e-bike is speeding up and if it's close to zero, it means the e-bike is maintaining its speed.
Bicycle acceleration is treated as very positive, positive, negligible, negative, and very negative. Fig. 3 shows the membership function for bicycle acceleration. To make a quality tree a method that can be used is the Logic Scoring of Reference [27].

### 2.1.4. Cadence Angular Acceleration

This an input that determine the effort the user is exerting on pedalling the e-bike. This gives the system a general idea on whether the user wants to accelerate, maintain speed, or slow down. When paired with the bicycle acceleration the system would be able to detect slopes and inclines and adapt to those situations.
Cadence angular acceleration is treated as very positive, positive, negligible, negative, and very negative. Fig. 4 shows the member ship function for cadence angular acceleration.

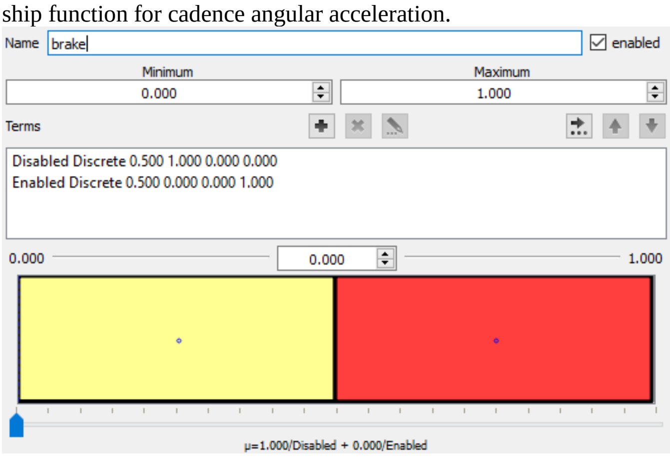


**Fig. 1:** Membership function for Brake


**Fig. 2:** Membership function for Human Power Significance

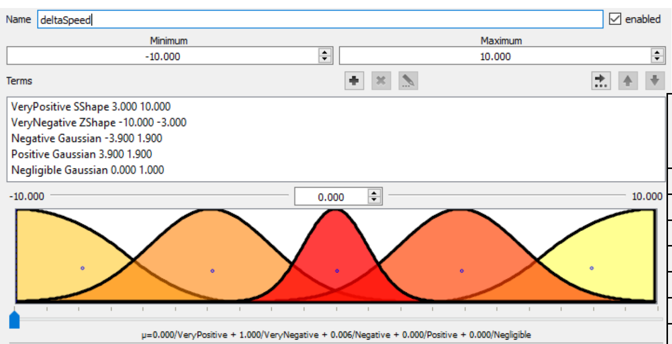


**Fig. 3:** Membership function for Bicycle Acceleration (deltaSpeed)

## 2.2. Output

The throttle is the output that changes how to motor will behave. It is a value that ranges from zero (0) to one (1) and these values determine the level of throttle the motor controller will provide to the motor, thus altering the predicted speed the user wants to achieve. The effect of the throttle output can vary based on the motor controller.

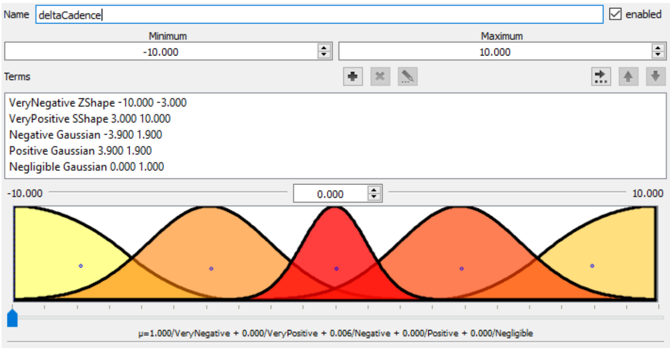


**Fig. 4:** Membership function for Cadence Angular Acceleration (deltaCadence)

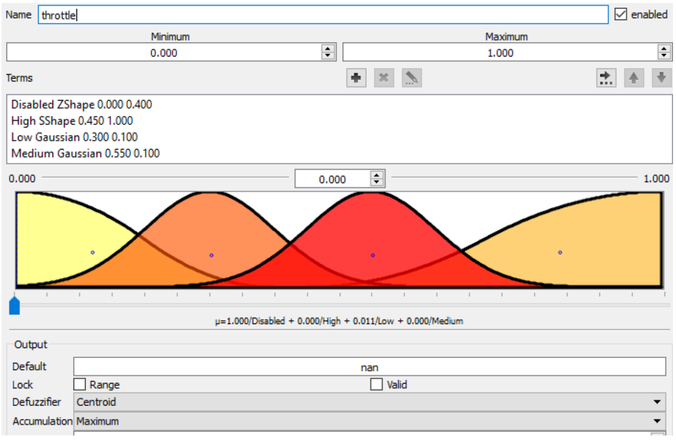


**Fig. 5:** Membership function for Throttle

## 2.3. Configuration

The design used the "Minimum" criterion for the AND method and the "Maximum" criterion for the OR method. "Minimum" criterion is used for the implication method, and the "Maximum" criterion is used for the aggregation or accumulation method. "Centroid" is used for defuzzifier as criterion to determine which x-value should be considered

## 2.4. Rules

Table 1 show rules when the brake is disabled and human power is significant. If Brake is enabled then Throttle is automatically disabled.

**Table 1:** Brake Disabled and Human Power Significant

| Bicycle Acceleration | Cadence Angular Acceleration | Output Throttle | Expected Scenario |
|---|---|---|---|
| Very Positive | Very Positive | Medium | Accelerate |
| Very Positive | Positive | Disabled | Maintain speed |
| Very Positive | Negligible | Disabled | Maintain speed |
| Positive | Very Positive | High | Accelerate |
| Positive | Positive | Low | Maintain speed |
| Positive | Negligible | Disabled | Maintain speed |
| Negligible | Very Positive | High | Uphill |
| Negligible | Positive | Medium | Uphill |
| Negligible | Negligible | Low | Maintain speed |
| Negative | Very Negative | Disabled | Slow down |
| Negative | Negative | Medium | Slight uphill |

| | | | |
|---|---|---|---|
| Negative | Negligible | Low | Maintain speed |
| Very Negative | Very Negative | High | Uphill |
| Very Negative | Negative | High | Uphill |
| Very Negative | Negligible | High | Uphill |

Table II shows rules when Human Power is insignificant.

**Table 2:** Brake is disabled and Human Power is Insignificant

| Bicycle Acceleration | Cadence Angular Acceleration | Output Throttle | Expected Scenario |
|---|---|---|---|
| Very Positive | Very Negative | Disabled | Downhill |
| Very Positive | Very Positive | Disabled | Downhill |
| Very Positive | Negative | Disabled | Downhill |
| Very Positive | Positive | Disabled | Downhill |
| Very Positive | Negligible | Disabled | Downhill |
| Very Negative | Very Negative | Low | Underpower |
| Very Negative | Very Positive | Low | Underpower |
| Very Negative | Negative | Low | Underpower |
| Very Negative | Positive | Low | Underpower |
| Very Negative | Negligible | Low | Underpower |
| Negative | Very Negative | Disabled | Slow down |
| Negative | Very Positive | Disabled | Slow down |
| Negative | Negative | Disabled | Slow down |
| Negative | Positive | Disabled | Slow down |
| Negative | Negligible | Disabled | Slow down |
| Positive | Very Negative | Disabled | Downhill |
| Positive | Very Positive | Disabled | Downhill |
| Positive | Negative | Disabled | Downhill |
| Positive | Positive | Disabled | Downhill |
| Positive | Negligible | Disabled | Downhill |
| Negligible | Very Negative | Disabled | Maintain speed |
| Negligible | Very Positive | Disabled | Maintain speed |
| Negligible | Negative | Disabled | Maintain speed |
| Negligible | Positive | Disabled | Maintain speed |
| Negligible | Negligible | Disabled | Maintain speed |

These data can be turned in to an information system as shown in [28]. Information Systems are software and hardware systems that support data for various applications [29].

# 3. Results and Discussions

The system was tested using the fuzzylite software with the following results.

## 3.1. Brake is enabled

When the brake is enabled, the output is expected to turn off the motor and produce no throttle. This is verified in the figure below where the brake was enabled and the other inputs were altered. Fig. 6 shows the response of the system in this scenario.

## 3.2. Uphill

When the rider is pedalling regularly and suddenly starts going uphill, the human power is significant and bicycle acceleration and cadence angular acceleration are very negative. To adapt to this scenario the throttle should be increased to help the biker. The first half simulates maintaining a speed while the second half simulates encountering an uphill. Fig. 7 shows the response of the system in this scenario.

## 3.3. Downhill

If the biker were maintaining a near-zero bicycle acceleration and the biker suddenly encounters a downhill, it is expected for the bicycle acceleration to increase and since the biker's cadence is at a constant rate, we can also expect the human power significance to return a '0' implying that the effort the human is exerting is not enough to have any effect on the speed of the e-bike any further. Fig. 8 shows the response of the system in this scenario.

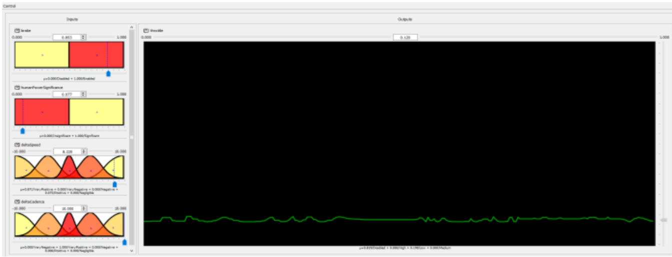

**Fig. 6:** Output throttle disabled when brake is enabled

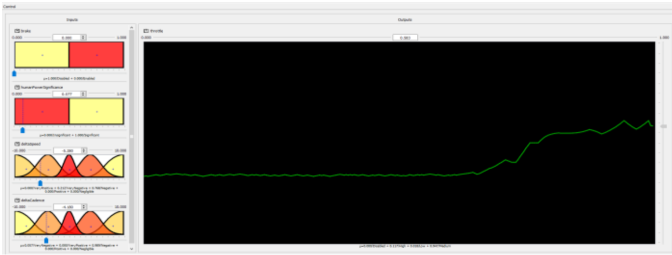

**Fig. 7:** Output throttle for uphill scenario

## 3.4. Accelerating on Flat Road

This simulates a case when the biker is at a constant speed, and then decides that he or she wants to start accelerating. This results in a positive bicycle acceleration and positive cadence angular velocity. Human power significance is '1' since this time since the rider is exerting more effort to move the e-bike. Fig. 9 shows the response of the system in this scenario.

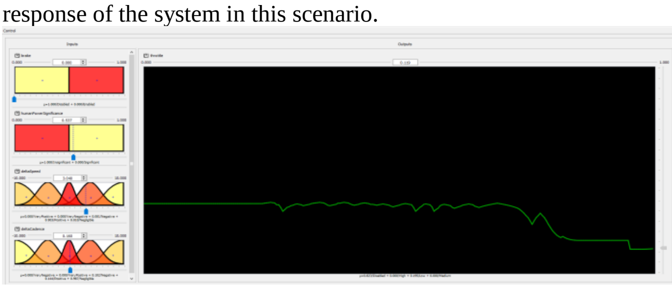

**Fig. 8:** Output throttle for downhill scenario

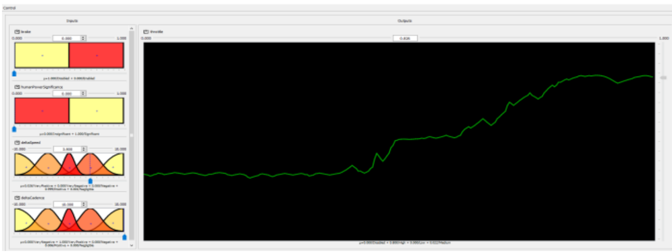

**Fig. 9:** Output throttle for accelerating on flat road

The expected result is that the motor will give the human more power to reach the desired speed. For communicating with the system it is suggested to use RFID [30] or usb data transfer [31] to send information. This is because an efficient system is ideal [32, 33]

## 4. Conclusion

By implementing fuzzy logic to a controller system for a pedal-assist electric bicycle, the researchers were able to come up with a system that is able to handle inputs which corresponds to the rider's cadence and bicycle acceleration and arrive at a desirable throttle output.

As future recommendations, the fuzzy inference system should be implemented on actual hardware for further testing in an actual electric bicycle setup.

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