# A Two-Wheeled Vehicle Navigation System Based on a Fuzzy Logic Controller

Endra Pitowarno [1], Diki Arya Nugraha [2]
Mechatronics Engineering Department [2]
Electronics Engineering Polytechnic Institute of Surabaya 60111
Telp. (+62)31-5947280 Fax (+62) 31-5946114
Email: epit@eepis-its.edu, [1] dikiaryanugraha89@gmail.com [2]

**Abstract**

*The paper deals with a two-wheeled vehicle, namely ESG-2 (Extended Segway-like Generation-2) navigation control system using a fuzzy logic controller. The vehicle employs two wheels left and right independently which are controlled independently using a fuzzy logic controller respectively. The controllers deal with a compact and implementable application for the normal using with a person (human with 60kg weight in average) loaded on the vehicle. A modified infrared-based range sensor system is applied to the vehicle as a tilt sensor and it is incorporated with an accelerometer to control its response in case of the dynamics disturbances. The fuzzy controller runs in tilt-mode while a reference tilt using a potentiometer (as steer system) is taken into account for navigating the vehicle. From the simulation using MATLAB ® and experiments it is obvious that the prototype of ESG-2 is quite challenging to be developed in the future.*

***Keywords**: extended segway-like generation-2, fuzzy controller*

## 1.Introduction

Dean Kamen (2001) [?] is the maker of two-wheeled vehicle, and made Segway PT, an electric, self-balancing human transporter with a complex, computer-controlled gyroscopic stabilization and control system. Two-wheeled vehicle appertain to a new vehicle like and this vehicle can stand by self because it has declivity sensor that detect the vehicle declivity. Two-wheeled vehicle is needed less energy to make it works it doesn't like common wheelchair. Two-wheeled vehicle will works when declivity sensor change. Two wheels installed in right and left sides, these wheels will move to forward or backward depend of declivity sensors and for navigation will uses steer data reference. The velocity of two wheeled vehicle depend of sensor change, it's like inverted pendulum principle which maintain the balance. In this research, the sensor system and navigation method will be investigated. The two wheeled vehicle needs declivity sensor and potentiometer (installed on steer). The declivity sensor is used for balance and velocity reference while potentiometer for navigation system.

Zadeh [2, 3] proposed a fuzzy set theory and fuzzy logic as a method for quantifying human qualitative evaluation indices. Mamdani [5] applied fuzzy control, which is an intelligent control, experimentally to a steam engine for the first time. The data from declivity sensor and potentiometer will be processed using a fuzzy control for navigation system and balancing a two wheeled vehicle. This method will be simulated and evaluated.

## 2. Previous Work

Many of two wheeled vehicles and or inverted pendulum models have been developed by researcher. For example, robot LEGO uses infrared-based range sensor for sensing the declivity and follow the line like line tracer being [3]. In this research an infrared-based range sensor GP2D12 system has been used to detect the declivity. The infrared-based range sensor installed in front side near castor.

This research used PID for balancing system and Fuzzy Logic for navigation. Many fuzzy logic controllers had used in two-wheeled vehicle and inverted pendulum [1]. In the case of [3] a fuzzy controller has to be used for combining the error of gyroscope and delta error of gyroscope for perform the vehicle going balance.

In this study ESG-2 uses a set of infrared-based range sensor and potentiometer-based sensor system to perform ESG2 maneuver as well but simple and cheap. As an initial trial a set of fuzzy rules has been introduced to keep the vehicle stable and easy to steer.

## 3. System Modeling

ESG2 has a principle like an inverted pendulum that maintains $\theta$ to 0. In other words ESG2 could be in a state of equilibrium by itself. Fig. 1 shows a model of a cart representing

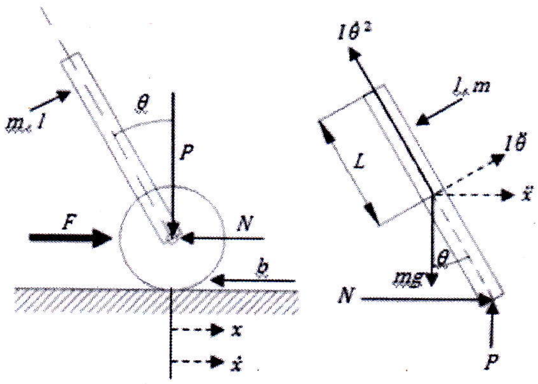


**Figure 1**: Simplification model of the system

This system has join point between cart and pendulum that can simplify the degree of freedom as shown in Fig.1. The wheel and the pendulum have one degree of freedom. The force F is:

$$F = M\ddot{x} \qquad \text{(Eq.1)}$$

or

$$\ddot{x} = \frac{F}{m} \qquad \text{(Eq.2)}$$

where

$$\frac{d^2x}{dt^2} = \frac{1}{M}\sum_{ESG2} Fx = \frac{1}{M}\left(F - N - b\frac{dx}{dt}\right) \qquad \text{(Eq.3)}$$

In case of rotational wheel,

$$\tau = I\ddot{\theta} \qquad \text{(Eq.4)}$$

or $$\ddot{\theta} = \frac{\tau}{I} \qquad \text{(Eq.5)}$$

where $I$ is inertia.
Combining Eq.5 to Eq.3 yields,

$$\frac{d^2\theta}{dt^2} = \frac{1}{I}\sum_{driver-and-ESG2} \tau = \frac{1}{I}\left(Nl\cos\theta + Pl\sin\theta\right) \qquad \text{(Eq.6)}$$

Both equations (Eqs.3 and 6) deal with Newton's Law number 3 which "For every action there is an equal of opposite re-action".

## 4. Design of Fuzzy Logic Controller for navigation system

The fuzzy logic used in this control is a simple Mamdani fuzzy approach that the input are data from infrared-based range sensor and potentiometer sensors while the fuzzy output is multiplication factor. Multiplication factor will multiply with potentiometer data and it will influence the velocity of right wheel and left wheel. Each wheels has rotary encoder for sensing the position and velocity of vehicle.

The infrared-based range sensor value (as in Fig. 2) and potentiometer value (Fig. 3) will be combined with fuzzy navigation and the output is a multiplication factor representing the actuation values to each motor.

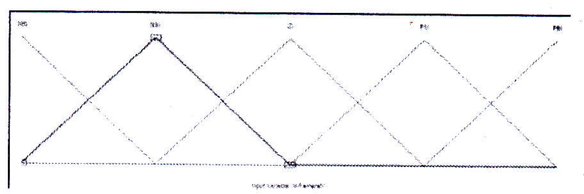

**Figure 2**: Membership function of infra red sensor

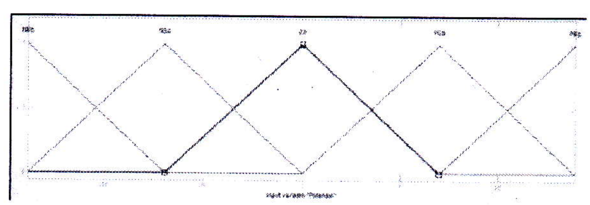

**Figure 3:** Membership function of steering system (potentiometer)

The infrared-based range sensor data consists of 5 memberships functions and also potentiometer consist of 5 membership functions.

It is noted that the value of steering system will affect to each motor (left and right) independently but simultaneously. So that a controller has to installed for each motor with a same control method.

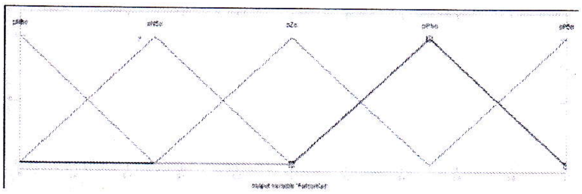

**Figure 4:** membership function of the output caused by steering system (represented by potentiometer)

In Fig. 4 the multiplication factor consist of 5 membership functions (*pnBo=negative BIG, pNSo=negative SMALL, pZo=ZERO, pPSo=positive SMALL, pPBo=positive BIG*) from 0 to 2. Output of fuzzy will be multiplied with steering value so it has two conditions for right wheel and left wheel. Each data will be added for balancing the body to perform ESG-2 turns left or turns right. Table 1 shows the total rules implemented to ESG-2, where im_ means infrared data and pt_ is data of potentiometer.

**Table 1**: Rules of Navigation using Fuzzy Logic

| | *pt_NB* | *pt_NS* | *pt_Z* | *pt_PS* | *pt_PB* |
|---|---|---|---|---|---|
| *im_NB* | *pZo* | *pNSo* | *pNBo* | *pNSo* | *pZo* |
| *im_NS* | *pPSo* | *pZo* | *pNBo* | *pZo* | *pPSo* |
| *im_Z* | *pPBo* | *pZo* | *pNBo* | *pZo* | *pPBo* |
| *im_PS* | *pPBo* | *pPSo* | *pNBo* | *pPSo* | *pPBo* |
| *im_PB* | *pZo* | *pZo* | *pNBo* | *pZo* | *pZo* |

Fig. 5 shows the simulink model of the system that has been simulated to perform the best rules that will be implemented to the vehicle.

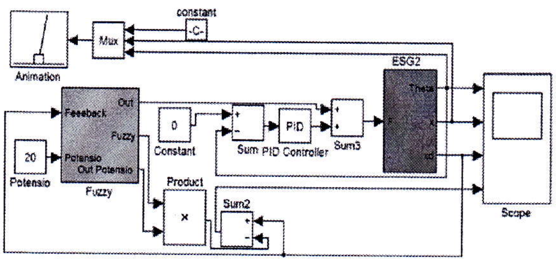


**Figure 5**: Simulink model of ESG2

## 4. Results and Discussion

This paper deals with the simulation but however, the system has succeed to be tested in an experimental. (the complete system of ESG-2 has been already tested to in an experimental work although it is not reported in this paper). Noted that the vehicle has no buffered memory system to record sensors and actuators data during run. Fig. 6 shows the experimental ESG-2 that has been developed in this study.

**Figure 6**: An Isometric view of ESG-2

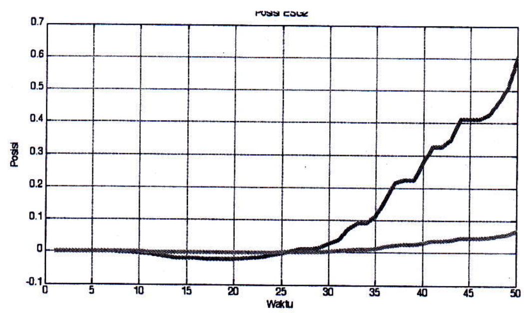


**Figure 7:** Position (displacement) *vs* steer value

Fig. 7 shows the correlation of displacement position (green line) and steering value (blue line). By increasing the steering value (potentiometer is rotated to particular direction) the vehicle will move to the correct direction. Noted that if only disturbing the c.o.g (center of gravity) of the vehicle by elevating the driver body to front will causing the vehicle moving straight forward. It works oppositely if the elevating going to rear.

The simulation also shows the correlation of velocity of vehicle and value of the steer as shown in Fig. 8. It is obvious that this steering system using a very simple method (potentiometer) has shown an easy implementation to the ESG-2.

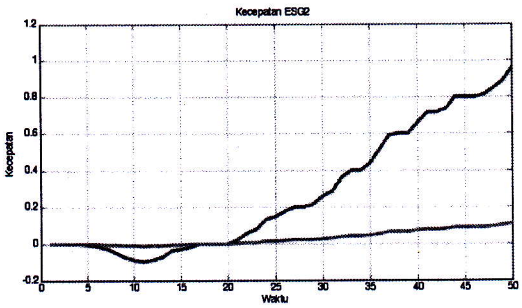


**Figure 8:** Position versus Velocity

A smoothness moving (turning) is also depicted as in Fig. 9. The moving of the particular wheel shows the changing of the heading of the vehicle.

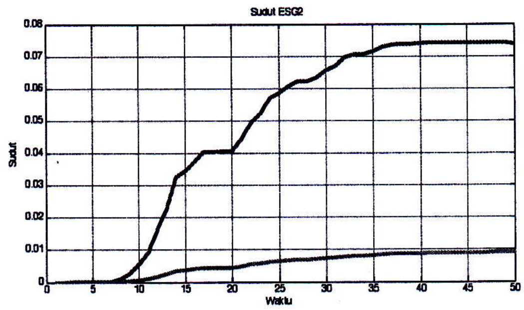


**Figure 8:** Position versus heading angle

## 5. Conclusion

From the simulation study it can be concluded that the model of two wheeled vehicle namely ESG-2 in this study has showed the success simulation in the case of testing the maneuver to move right or left. It is also shown in the experimental testing by loading the vehicle with a person with weight of around 60 kg. The simple range sensor based on infrared has shown the simplicity in stabilizing the movement when the steer (value) is added by driver.

## References

[1] Ching, C. (2007). Fuzzy Controller Designed by GA for Two-wheeled Mobile Robots. *International Journal of Fuzzy Systems,* 9(**1**).

[2] Zadeh, L. A. (1988). Fuzzy Logic. *IEEE Computer*. 83-93.

[3] Zadeh, L. A. (1996). Fuzzy Logic = Computing with Words. *IEEE Trans. Fuzzy Systems*. 4(2). 103-111.

[4] Kuswadi, S. (2007). Kendali Cerdas, Penerbit ANDI, Jogjakarta.

[5] Grasser, F. (2002). JOE: A Mobile, Inverted Pendulum", IEEE Trans. On Industrial Electronics. 49(**1**).