# Inverted Pendulum Human Transporter Balance Control System Based on Proportional Integral Derivative – Active Force Control

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**Abstract**

*Many research for the balancing of inverted pendulum control system to develop the performance. This paper will simulate a Proportional Integral Derivative – Active Force Control (PID-ACF) methods to swing a pendulum attached to a cart from an initial downwards position to an upright position and keep that condition stable and implemented to the segway chair human transporter. The combined control between PID and AFC system is used to maintain the actual acceleration is affected by disruption of the references given, because external disturbance can affect the system. For the experimental it will compare the performance between using a classical control PID and PID-AFC.*

Keywords: inverted pendulum, Active Force Control, segway.

## 1. Introduction

The inverted pendulum system is similar with standing motorcycle. The high acceleration will affect the angle of the vehicle. Inverted pendulum is a pendulum system which center of mass is above the pivot so that balance can be achieved is an unstable equilibrium. This balance is not easily achieved. To measure the angle of the pendulum it need proximity sensor that in this case used infra red sensor that measure the distance of pendulum pivot to the ground. So from the distance that can be measure the degrees of the pendulum. The inverted pendulum system is a standard problem in the area of control systems. Many control algorithms used to solve this problem such as PID controllers, neural networks, fuzzy control, genetic algorithms, etc. This paper will simulate a Proportional Integral Derivative – Active Force Control (PID-ACF) methods to solving inverted pendulum control problem.

Load or disturbances in actuator on the controller system is basically the active power against the power generated by the motor shaft. Active Force Control is a terminology of robust control scheme that is practical [1] [5]. A concept of control at the level of effective acceleration compensates, reject and cancel the disturbance signal on the output torque of the actuator. Based on the feedback of actual acceleration [3]. This idea is based on the basic concepts of the second newton law. In the inverted pendulum system the external disturbance to wheel that affect the actuator will be annoying the balance system.

## 2. System Modeling Inverted Pendulum

Figure 1 shows the schematic system of the inverted pendulum human transporter. It is consider that the horizontal position of the cart, $x$. The length of pendulum, $L$ and pendulum angle, $\theta$.

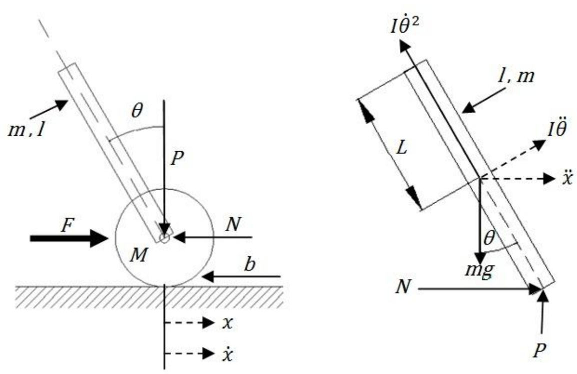


**Figure1**. Schematic diagram of inverted pendulum

Summing the forces in the Free Body Diagram of the cart in the horizontal direction, will get the equation of motion like :

$$F = M\ddot{x} + b\dot{x} + N \quad (1)$$

Summing the forces in the Free Body Diagram of the pendulum in the horizontal direction, you can get an equation for N and P as like:

$$N = m(\frac{d^2x}{dt^2} + L\sin\theta\left(\frac{d\theta}{dt}\right)^2 - \cos\theta\frac{d^2\theta}{dt^2}) \quad (2)$$

$$P = m(g - L\cos\theta\left(\frac{d\theta}{dt}\right)^2 - \sin\theta\frac{d^2\theta}{dt^2}) \quad (3)$$

These equations are nonlinear, but since the goal of a control system would be to keep the pendulum upright the equations can be linearized around $\theta \approx 0$.

$$\frac{d^2x}{dt} = \frac{1}{M}\sum F_x = \frac{1}{M}\ (F - N - b\frac{dx}{dt}) \quad (4)$$

$$\frac{d^2\theta}{dt} = \frac{1}{M}\sum\tau = \frac{1}{M}\ (NL\cos(\theta) + PL\sin(\theta)) \quad (5)$$

The physical constraint (the pin joint) between the cart and pendulum which reduces the degrees of freedom in the system. Both the cart and the pendulum have one degree of freedom (X and theta, respectively).

### 3. Pendulum Angle Measurement

The level of the pendulum angle can be measured by distance of object to the ground. With vertical position with infrared distance sensor.

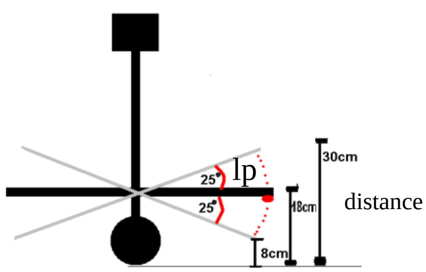


**Figure2.** Infrared proximity for sensing the angle

From Figure 2 it can be seen the angle using infrared distance sensor proximity on an inclined plane can be formulated in the following equation:

$$\theta = arc\sin\frac{distance}{lp} \quad (6)$$

### 4. Active Force Control

Disturbance on the actuator system essentially is an active force that against the forces generated by the motor shaft. Power generated by motor or actuator generally in a power control system is a output power based on algorithm or methods used. The more responsive the output power due to disturbance and effects of load the better the control is. Thus, any movement in the robotic control scheme that consider load or disturbance in its operations can be categorized as a scheme of force control [3].

The advantage of AFC is the way to eliminate the external disturbance practically. It is practical because the mathematical complexity is reduced significantly since it operates either on the physical measurements of relevant parameters or on the estimated parameters[2]. Besides, the computational burden is much reduced and hence it can be easily implemented in real-time. For the segway system used in the study with reference to the trolley component and from Newton's second law of motion:

$$\sum F = m.a \quad (7)$$

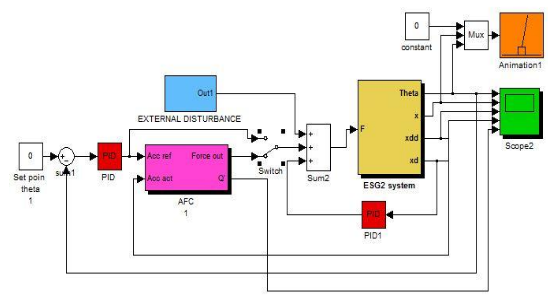


**Figure3**. Schematic PID and PID-AFC on simulink

The trajectory is the desired pendulum angle of the driver. The most important equation for the AFC scheme is to obtain the estimated disturbance force in the AFC as seen in figure 8 bellow:

$$Q' = F_{ref} - M.\ddot{x}_{act} \quad (8)$$

### 5. Control System Design

The control system design that is built consists of several sensors and actuators which support the proposed methodology, in this case PID and AFC. The sensors used are infrared as tilt, accelerometer for acceleration sensor, current sensor for torque value proximity, rotary encoder used to count destination and velocity, and the last is weight sensor. The actuator is 2 DC motor for trolley, hoist, and rope mechanism. This is the formulation of PID and AFC as like:

$$u(t) = K_p e + \int_0^t e(\tau)\,d\tau + T_d\frac{d}{dt}e(t) \quad (9)$$

$$AFC = Force\ ref - Actual\ Force \quad (10)$$

$$Actual\ Force = m\ x\ a \quad (11)$$

$$Force\ ref = \frac{ixKtn}{r} \quad (12)$$

From the equation above, the PID-AFC controller will be designed with equation as like:

$$C = Kp.Error + Ki.iError + Kd.dError + AFC \quad (13)$$

## 6. RESULT AND DISCUSSION

This part will report the result of experiment on the plant based on control system design. The program for controller is in accordance with the proposed control method. This experiment has a purpose to know the robustness of the system. The first experiment is done using PID control by tuning the Kp, Ki, and Kd at first. Then the second experiment is done using AFC. With this experiment, it will be known the characteristic of each controller. To know the different performance between PID and PID-AFC, the force disturbance raised until different performance with the target is angle of pendulum = 0. The data parameter is Mass of cart = 46.5kg, Mass of pendulum = 60kg, friction = 0.1N, Length of Pendulum 0.27m, Inertia= 8.128kg/m². and the force disturbance is tuning until significant different performance. The graphic result as like:

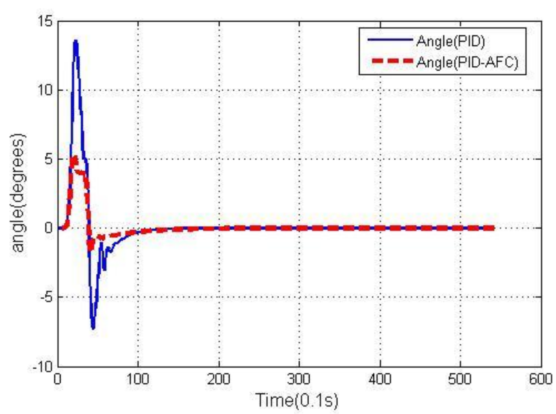


**Figure4**. angle vs time with optimum disturbance

The performance using PID-AFC can reduce the error cause of external disturbance to the cart efficiently than using PID.

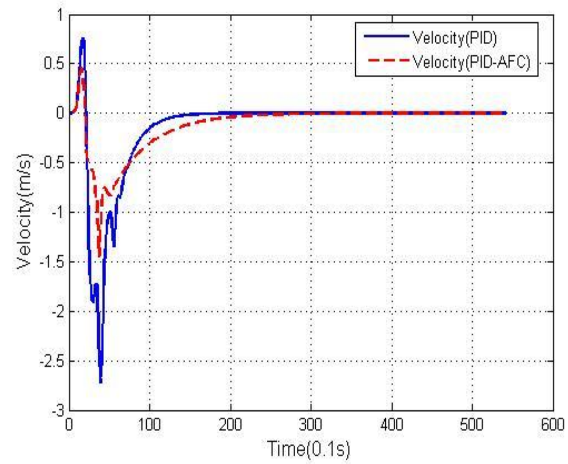


**Figure5**. velocity vs time inverted pendulum

The performance using PID-AFC is smoother than using PID.

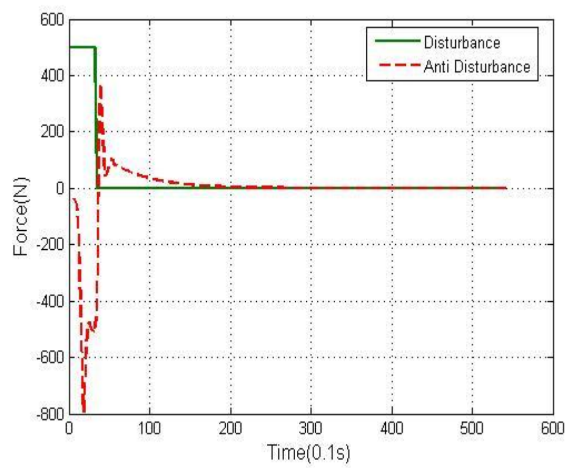


**Figure6**. Disturbance and anti disturbance

Red line is value of disturbance estimation from the AFC, this data will be proceed at AFC controller. Like with velocity graph like figure number 4, it seems AFC controller can raise the smooth level of performance. If the disturbance value is raised, the performance without AFC is worse.

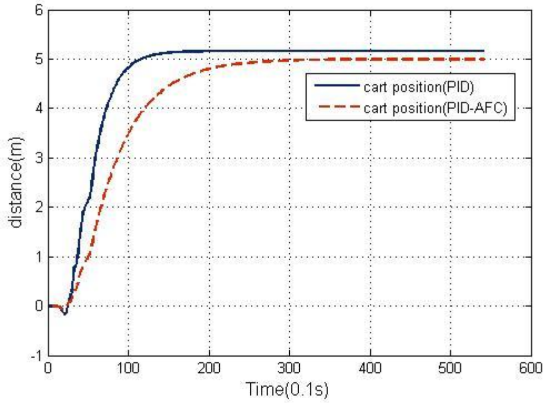


**Figure7**. distance vs time inverted pendulum

## 7. CONCLUSION

An inverted pendulum human transporter has been demonstrated. Under tuning the disturbance to be lifted and operation setting the experiment results show the differently and good performance of the inverted pendulum human system with the AFC method compared to PID control. This clearly implies that the AFC method is very effective and robust control system. From the experiment The time required to reach the reference of pendulum angle is the same that about 10 second but the percentage of error is decrease very excellent.

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