## Self-Equilibrium Control on a Dynamic Bicycle Ride

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*Abstract:* - It is very important for a biker to ride comfortably and safely around everywhere. Through analyzing the stability characteristic of a bicycle when it was driven on each sloping road, the position of the center of gravity (COG) was commonly one of the key influencing factors. Therefore, this study presented a simple approach to measure the inclination degree of sloping road and fed to the system controller for changing the COG position. Moreover, the front-to-back adaptive equilibrium control of a bicycle ride was controlled by means of a hysteresis algorithm, and built in a control unit. The COG position of a whole bicycle system allowed to be changed by either manual or automatic mode which was completely dependent upon biker decision. For convenience, an experimental prototype had first been established in the laboratory. Later, several experiments, such as the feasibility and flexibility concerning system control structure were related to a bicycle were performed on the prototype. Simulation and experimental results showed that the dynamic equilibrium of a bicycle when it was driven on each sloping road could be controlled by using the posture control approach proposed in this paper. In addition, the increasing cost concerning additional facilities was cheap and easily retrofitted into the existing bicycles.

Key-Words: - Bicycle, Center of gravity, Hysteresis controller, Sloping road, Equilibrium control, Cost.

## **1** Introduction

In recent years, there is growing concerns with bicycles in our daily life as a result of their outstanding advantages, such as energy saving, high energy efficiency, and facility of maintenance. Bicycles have also been attracting more and more attention result from transportation without any environmental burden. Especially, it is the best charming thing for many peoples that a bicycle ride would increase their health. However, bicycle is unstable when it not controlled and it will fall down without human assistance like steering handle or moving upper body. It requires in general many trials and much time to learn.

Research studies were carried out a bicycle and its performance characteristic analysis of a dynamic motion have been performed for many years [1]-[6]. According to the characteristics of these studies which could be commonly divided into two main aspects: the first aspect was concerning theoretical studies that were started as early as ten years ago by lots of scientists. In the early's of 1970, Sharp [7] developed a bicycle dynamic model, named as Sharp model, it was complicated and not easy to be applied to design bicycle posture controller. A feedback control law and bicycle model were derived by Getz [4], which caused a nonlinear, nonholonomic, non-minimum phase model of a unmanned powered two-wheel bicycle obtained a stably tracking on a arbitrary smooth trajectories of roll-angle non-zero velocity. Getz and his coworker presented a first controller, which allowed tracking of arbitrary trajectories while maintaining balance. Under rider control conditions, Later Getz further applied the internal equilibrium control of the problem of path-track with balance for the bicycle by using steering and rear-wheel torque as inputs, and also proposed a bicycle model [8]. In 2002, Lee and Ham [9] presented a control algorithm for the self-stabilization of the unmanned bicycle by using nonlinear The control. second aspect was concerning practical studies had been relatively scarce with regard to another aspect, for example Miyamoto [10] implemented the trial of autonomous bicycle robot for a short time period. In addition, there are several researchers begun to study the expert control of a bicycle, Chen who used the fuzzy intelligence to a electric-power bicycle [2][3], named as Elebike, which was designed and then a bicycle could be automatically controlled by the swivel handle.

On the basis of the nonlinear characteristics in a bicycle robot dynamic system, thus make the bicycle robot control much more difficult. Several researcher were carried out using each intelligent control approach such as fuzzy sliding-mode control, adaptive neuro-Fuzzy control to stabilize autonomous bicycle [11][12]. Additionally, Ham and Cho who utilized the lateral motion of mass and suggest a control algorithm for steering angle and driving wheel speed for a given desired path. They also suggested a new algorithm for nonlinear inverse kinematic problem which was similar to Piccard's iterative method in basic concept to stabilize bicycle. In practical aspect, Yamakita, et al. proposed a trajectory tracking and balancing control for autonomous bicycles with a balancer, an inputoutput linearization is applied for trajectory tracking control and a nonlinear stabilizing control is used for the balancing control [13]. As mentioned above studies, even though the control results for

studies, even though the control results for stabilizing an autonomous bicycle might be better, but these controlling approaches are generally too complex and expensive to be implemented. To protect bicycle falling down when it was

ongoing, environmental information should be specially considered. This paper focuses the attention on a posture control approach for a biker under various environments. The control strategy is divided into two aspects; the first aspect is to design a scheme for measuring the gradient of the sloping. The second aspect deals with the gait for a bicycle to be safely driven on a sloping. To maintain a bicycle static stability, it requires that the center of gravity (COG) should be always controlled within the supporting area of bicycle. For the purpose of this study, a riding posture for a biker in the sagittal plane can be controlled by an innovative system controller configuration.

## 2 The Mechanism of CTUbike Bicycle

In order to carry out concerning experiments which were mentioned in this paper, the CTUbike bicycle was first constructed at Chienkuo Technology University. Its falcilities were installed as shown in Fig. 1(b). A pair of potentiometer was used to measure the inclination angle of the road; one was attached on the head tube, while the other one was installed beneath the saddle. The latter one was also mechanically linked with the shaft of a dc motor. For convenience, there is no difference exists for bicycle driven on a ground level or on a sloping road in the frontal plane. Consequently, this study will be concentrated on the sagittal plane.

#### 2.1 The Structure of CTUbike Bicycle

Fig. 1 shows the photograph of a completed prototype and the illustration of CTUbike bicycle. The facilities are related to the CTUbike bicycle is respectively introduced in Fig. 1(b).

Most of the CTUbike mechanism is similar to a traditional popular bicycle. In theory, the supporting area of a bicycle system is formed by the points of contact between front and rear wheels and ground. However, in case of the position of the center of gravity of a whole bicycle system was always controlled in this supporting area, a safe and comfortable ride would be achieved for bikers. For the purpose of obtaining a safe and comfortable dynamic riding, the traditional bicycle system should be modified in mechanism and added several facilities for implementing the adaptive control mission. There is a dc motor installed beneath the saddle, and the shaft of dc motor is directly couple with the supporting frame of saddle. The rotation direction and angle of dc motor varies with the type of sloping roads and their inclination angle. Using a potentiometer to dynamically measure the inclination angle of bicycle, and then fed to the system controller for adjusting the rotation direction and angle of dc motor. The position of center of gravity of a whole bicycle system was controlled by the rotation direction and angle of saddle or dc motor. In other words, in order to achieve a comfortable ride and fail to upside down during bicycle riding, the biker posture was generally one of the key influencing factors. Taken the manufacturing cost into consideration, the system dynamic equilibrium control of a bicycle is made by a control unit which is composed of some hardware electronic circuits.



Fig. 1. (a) showing completed photograph of CTUbike bicycle (b) and facility designation.

#### **2.2 Reasons of Positioning the Components**

In order to complete the dynamic posture control of biker during bicycle riding, some additional components was necessary, such as a sensing unit was used to dynamic sensing the inclination angle of sloping road, a dc motor was used to adjust the inclined angle of saddle, a battery was applied to all control units and a control unit which was used to drive and control the rotation angle and direction of dc motor. The designing objective and operating principle of these additional facilities would be described respectively in the following:

Potentiometer: A potentiometer was attached to the top stainless steel pipe of front wheel (head tube) and its shaft also suspending a pendulum to dynamically sense the inclination angle of the sloe surface. Initially, pendulum would lie in a position, where was called start point, due to the gravity force effect. In case of the bicycle was driven on a sloping road, the inclination angle of the sloping road would be immediately sensed by the potentiometer. By using a special pendulum mechanism, the inclination angle of sloping road was sensed by potentiometer and output a corresponding direct voltage. At the same time, this real-time sensed direct voltage would feed to the system controller. According the default setting, the rotation angle and direction of dc motor or saddle would be controlled by system controller.

DC motor: Either the bicycle system was safe or upside down, it depended on the position of center of gravity of a whole bicycle system. In this paper, in order to compensate for the position of center of gravity center out of supporting area (safe area), the biker posture would be adjusted according to the type of sloping roads and inclination angle. A dcmotor was installed beneath the saddle and linked with the saddle. Once the inclination angle and the type of sloping roads were determined, the system controller then commanded the dc motor to rotate in the opposite direction with the same angle as the potentiometer had sensed. The rated output torque of dc motor should be designed enough to drive biker's body forward or backward inclination when a bicycle was driven on a sloping road. Since it is important for the total volume and weight of the dc motor to be controlled as low as possible; therefore, a gear train was coupled with the rotor shaft of dc motor for reducing speed.

**Battery**: In general, there are two types of bicycle, with and without power assisted bicycle. Since the Nickel-hydrogen (Ni-H) battery essentially possessed high energy density characteristics; a rated voltage is 12V Ni-H battery is adopted in our experimental bicycle.

**Control unit**: The dc-motor torque was controlled by hysteresis controller. A sufficient power was supplied through a dc-power amplifier. Because of the resonance mode of the dc motor control and acoustic noise might be excited result from the frequency change. The amplifier was designed to have a constant switching frequency, such a switching amplifier was called PWM (Pulse Width Modulation) amplifier, and here only the width of the pulses would vary with the load.

# **3** Equilibrium Analysis on Different Sloping roads

As mentioned in the preceding section, since in the frontal plane almost no difference exists for bicycle dynamic driven on a level or sloping road, so that we will concentrate our attentions on the bicycle driven gait in the sagittal plane. Fig. 2 shows the angle definition of the inclination of the sloping road. In general case, the sloping road may have an unpredictable gradient in the direction of driving. But both the level and slope do not have inclination in the frontal plane of the bicycle. Here we define that the frontal plane is perpendicular to the direction of motion.



 $<sup>\</sup>alpha$ : the inclination angle of the sloping road

## Fig. 2. Illustrating the sloping road and inclination angle definition

Because of the lack of an available mechanism for a bicycle driven on a sloping road, our study had to start from an investigation of a bicycle driven on a level ground, on an ascending slope surface, and descending slope surface. From the analysis, we obtained a generally stably and efficient driven gait for a bicycle. This will be the main topic of the next section.

In order to create an algorithm for controlling a bicycle in a sloping driving gait, we must first analyze the bicycle driven pattern. Firstly, some assumptions are made and described as follows:

(1) The diameter of the bicycle's front wheel and rear wheels are equal.

- (2) The form of the front wheel and rear wheel is circle.
- (3) The projecting distances from the COG to either the front or rear wheel on the x axis is equal.
- (4) The center of rider's body can be represented by a particle.
- (5) The front and rear wheels of the bicycle are constrained to roll without slipping.
- (6) There is no difference exists in the frontal plane. Consequently, sagittal plane motions are of most importance to this study.
- (7) Strictly speaking, when a bicycle is driven on a sloping road is a static motion, not dynamic motion. Because of that the ZMP of the bicycle always is located on the contact line.
- (8) In the analyzing the motion of bicycle period, the environmental parameters and rider's motivation are not considered.
- (9) The weight of supporting tubes, which are distributed in the bicycle, can be neglected for simply analyzing bicycle motion behaviors.

#### **3.1 Bicycles Driven on a Flat Ground Level**



Fig. 3. A bicycle was driven on flat ground level.

The symbols were labelled on Fig. 3 are respectively defined as follows:

- $m_1$ : is the mass of front wheel;
- $m_2$ : is mass of rear wheel;
- $m_3$ : is the equivalent mass of a biker;
- $\lambda$ : is the distance on the x axis between the projection point of COG of a whole bicycle system and the COG projection points of the front wheel or the rear wheel;
- $w_1$ : is the weight of front wheel;
- $w_2$ : is the weight of rear wheel;
- $w_3$ : is the weight of a biker;

- $\ell$ : is the distance between the center of mass of the biker and saddle;
- $\ell_1$ : is the distance on the x coordination between the projections of the front wheel and the rear wheel;
- $x_{C.G}$ : is the projection location of COG of a whole bicycle system on the x axis;
- $x_1$ : is the projection location of front wheel on x coordination;
- $x_2$ : is the projection location of rear wheel on x coordination;
- $x_3$ : is the projection location of the rider's saddle on x coordination;

For convenient analysis, the static motion for a bicycle driven on an even terrain can be divided into following phases;

**Phase 1:** As shown in Fig. 3, the bicycle was driven on an even terrain, the center of gravity of front wheel, rear wheel, and biker's body are projected into the x coordination,  $x_1$ ,  $x_2$ , and  $x_3$ , respectively. We could find the location of the center of gravity (i.e. COG) of bicycle  $x_{C.G}$  is almost overlapped with the projected point of the center of gravity of rider  $x_3$ . If the bicycle wanted to be stably driven on level ground, the resultant moments should have an equilibrium relation. The COG of the bicycle  $x_{C.G}$  could be expressed as follows:

$$Mx_{C.G} = \sum_{i=1}^{3} m_i x_i$$
 (1)

where M is the total weight of the bicycle;  $x_i$  is the distance between the rear-wheel, front-wheel and the COG of the bicycle, respectively;  $m_i$  is the center of mass of the rear-wheel, front-wheel, and rider.

Rearranging (1) to form a more simple representation, it was given by

$$x_{C.G} = \frac{\sum_{i=1}^{3} m_i x_i}{M}$$
(2)

**Phase 2:** Under the constant environmental conditions, the bicycle could always obtain a sufficient driven efficiency and stability. It is unnecessary to change the COG of the biker for improving the bicycle's stability here.

**Phase 3:** The COG of the bicycle was located in the center position of the contact line. As shown in Fig. 4, a pseudo circle was formed and where the radius r was the length from the COG to front hub. According to the conservation of angular momentum, if there is a rigid rotating around a fixed shaft and the net external torque was zero, then the amount of the angular momentum reacted on the rigid was given by

$$\tau = \frac{dL}{dt} = 0 \tag{3}$$

and

$$L = mr^2 \omega \tag{4}$$
$$= I\omega$$

where L is the angular momentum, which was always kept constant here, it also could be represented in (4); I is the momentum of a whole bicycle;  $\omega$  is the angular velocity of pseudo circle. Equation (4) showed that the stability of a bicycle depended on the number of radius r. That means the bicycle driven on a flat ground level was not easy to fall down in the front plane.



Fig. 4. Angular momentum analysis for a bicycle driven on a ground level

#### 3.2 Bicycles Driven on an Ascending Slope

Fig. 5 showed that a bicycle was driven on an ascending slope. The definition of symbols which were labeled on the Fig. 5 was similar to that of Fig. 4.

When a bicycle was driven on a sloping road, there is an inclination angle  $\delta$  existed between contact-line and ground level. The forces owing to the gravitational effect on the components were perpendicular to the ground level; it was divided into two  $\vec{x}$  and  $\vec{y}$  parts, respectively. The COG projection of a whole bicycle on x axis then was obtained from that of  $\vec{x}$  parts of each component and given by

$$x_{C.G} = \frac{(m_1 x_1 + m_2 x_2 + m_3 x_3) \cos \delta}{m_1 + m_2 + m_3}$$
(5)

As seen in (5), the more the inclination angle  $\delta$ , the less value did  $cos \delta$ . The COG position of a whole bicycle system  $x_{C,G}$  was shifted to the origin of the reference coordination. The equivalent inertia moment of a whole bicycle system became less with respect to the center of rear wheel. This means that bicycle was easy to fall down.



Fig. 5. A bicycle was driven on an ascending slope.

According to the physics principle, in order to improve the stability of a bicycle ride, the COG position of a whole bicycle system would be simply moved forward in the driving direction by inclining biker body forward, as shown in Fig. 6. In other word, if the projection location of biker on the x axis moved away the center of rear wheel as possible as, the dynamic stability of a bicycle ride was achieved due to the equivalent inertia moment with respect to the center of rear wheel increased, and the final COG position of a whole bicycle could be represented as follows:

$$x_{C.G} = \frac{(m_1 x_1 + m_2 x_2) \cos \delta + m_3 \cos \delta (x_3 + \ell \sin \beta)}{m_1 + m_2 + m_3}$$
(6)

where the angle  $\beta$  represented the inclined forward angle of biker.



Fig. 6. The COG position of a whole bicycle system was modified by moving biker body forward in the driving direction.

#### 3.3 Bicycles Driven on a Descending Slope

Fig. 7 showed that a bicycle was driven on a descending slope. The definition of symbols which were labeled on the Fig. 7 was similar to that of Fig. 4.



Fig. 7. A bicycle was driven on a descending slope.

To observe the Fig. 7, it is easy to upside down due to the COG position of a whole bicycle system is too near the contact point of front wheel. Resulting in the inertia moment of the pseudo circle decreased significantly. In this case, the biker body should be moved backward, as shown in Fig. 8, to improve the bicycle ride.

When a bicycle was driven on a descending slope, and assumed that there is an inclination angle  $\eta$ between contact-line and ground level. The COG projection of a bicycle on x axis also can be obtained from that of  $\vec{x}$  parts of each component and given by

$$x_{C.G} = \frac{(m_1 x_1 + m_2 x_2 + m_3 x_3) \cos \eta}{m_1 + m_2 + m_3}$$
(7)

The COG position of a whole bicycle system  $x_{C.G}$  was dependent on the inclination angle  $\eta$ . It showed that would shift away the origin of the reference coordination. The equivalent inertia moment with respect to the center of front wheel became less. This means that bicycle was situated at an unstable status, and it was easy to fall down.

As mentioned above case, the stability of a bicycle ride was improved by changing the biker posture. The COG position of a whole bicycle system should be moved backward in the driving direction by inclining biker body backward, as shown in Fig. 8. After compensation had been completed, the equivalent inertia moment with respect to the center of front wheel was increased since the final COG position of a whole bicycle system was moved away the contact point of front wheel. The expression of the COG position on x axis could be expressed by

$$x_{C.G} = \frac{\left(m_1 x_1 + m_2 x_2\right) \cos \delta + m_3 \cos \delta \left(x_3 - \ell \sin \sigma'\right)}{m_1 + m_2 + m_3}$$
(8)

where the angle  $\sigma'$  represented the inclined backward angle of biker.



Fig. 8. The COG position of a whole bicycle system was modified by inclining biker body backward in the driving direction.

#### **4** Controller Design

If there was a larger inclination angle between sloping road and ground level, thus it is difficult for

a biker to apply force to pedal. Not only biker easily felt fatigue, but also he/she would consume much more energy during a bicycle ride on sloping road. In this paper, a simple and low cost control strategy was proposed based on a sensory subsystem dynamically measured the inclination angle of the sloping road as well as fed back to the control unit. By regulating biker upper body posture inclined forward or backward in the sagittal plane, the stability of a whole bicycle system would be improved significantly [10]. Due to the projected position of the bicycle's COG on the x-axis moved toward to the center of the contact line, thus the inertia moment increased with respect to the center of lower wheel of the bicycle. Regardless of the inclination angle value of the sloping road, no matter when only the normal line of the saddle was controlled by control unit always parallel to that of the ground level. Thereafter, the saddle and chain wheel of the bicycle was seemed as to form a rigid body, the biker would feel comfortable when he/she ride a bicycle on a sloping road was similar to ride on a horizontal road.

#### **4.1 Sensory Circuit**

The measuring structure of the inclination angle of a road was shown in Fig. 9. A linear potentiometer was acted as the inclination angle measuring component for a road here and installed beside head tube. As seen in Fig. 9, it showed that the shaft displacement of the potentiometer had different rotation direction when the bicycle was on the ascending slope or descending slope, respectively. Notice the point which was labelled, o, also called as balance point, it represented that bicycle was situated at flat ground level (horizontal road), and outputted a reference voltage value.



Fig. 9. Sketch of a linear potentiometer was used to measure the type of terrain and its inclination angle.

Since the effects of the gravitational force on the pendulum, the pendulum always moves toward the ground. The rotating angle of the shaft of linear potentiometer depended on the number of inclination angle of a sloping road. On the descending road, the inclination angle was a positive angle. On the ascending road, the inclination angle was then a negative angle.

#### 4.2 Controller for Adjusting COG Position

According to working necessities of the system, the system configuration of the controller was illustrated in the Fig. 10. The hysteresis controller output signal was modulated by using PWM (Pulse Width Modulation) technology due to the energy-saving factor was taken into account. For the purpose of increasing the output torque and compact the total volume of dc servo motor used as possible as. In addition, the control unit was composed of simple and cheap analogue hardware circuit. Therefore, the manufacturing cost of control unit would be cost down greatly, and the system was easily implemented.



Fig. 10. System configuration of the controller.

The input variable of the hysteresis controller was the amplified voltage error value between reference voltage and feedback voltage  $\Delta e(t)$  was obtained and represented by

$$\Delta e(t) = K(\theta_r(t) - \theta_f(t))$$
(9)

where the parameters in (9) were defined as follows, respectively.

 $\Delta e(t)$ : is the error voltage [V]

- *K* : is proportional constant [V/rad.]
- $\theta_r$ : is the reference angle [rad.]
- $\theta_{f}$ : is the actual angle [rad.]

The dynamics and circuit dynamics were expressed as follows [6]:

$$J_m \frac{d^2 \theta(t)}{dt^2} + D \frac{d \theta(t)}{dt} + T_L(t) = T_m(t)$$
(10)

$$K_e \frac{d\theta(t)}{dt} + L_a \frac{di_a(t)}{dt} + R_a i(t) = u$$
(11)

$$T_m(t) = K_i i_a(t) \tag{12}$$

where the parameters in (10), (11) and (12) were defined as follows:

 $T_{I}(t)$ : is load torque [N-m]

 $T_m(t)$ : is generated by dc motor [N-m]  $i_a(t)$ : is armature current [A] u: is the control input voltage [V]  $\theta(t)$ : is the rotor placement [rad.] J: is the inertia moment [N-m-sec.<sup>2</sup>] D: is the friction coefficient  $K_e$ : is the back emf. constant [V/rad./sec.]  $K_i$ : is the torque constant [N-m/A]

Because of the electrical time constant was in general much smaller than the mechanical one, the delay of electrical response could be neglected here for convenience. Where the parameter  $B_m$  was the viscous-coefficient, and due to the friction coefficient was small so that it was neglected here, the viscous-coefficient could simply be represented as

$$B_m = \frac{K_e K_i}{R_a} \tag{13}$$

Generally speaking, the mechanism of the torsional spring constant value between the gear box and the load (namely saddle) was very large, thus assumed that it was approaches to infinity. Therefore, a simplification transfer function form of the dc motor position control system could be expressed as follows [14]:

$$\frac{\theta_o(s)}{\theta_r(s)} = \frac{E}{As^3 + Bs^2 + Cs + E}$$
(14)

where the abbreviate transfer function form in (14) the parameters respectively defined as follows,

$$A = JL_a \tag{15}$$

$$B = R_a J + B_m L_a \tag{16}$$

$$C = R_a B_m + K_i K_e \tag{17}$$

 $E = KK_s K_i n \tag{18}$ 

A constant voltage source was applied on the two fixed terminals of linear potentiometer. Fig. 11(b) showed the sketch of saddle response when the bicycle was driven on an ascending slope (uphill) road. Fig. 11(c) showed the sketch of saddle response when the bicycle was driven on a descending slope (downhill) road condition.



Fig. 11 Saddle and potentiometer response (a) front view (b) side view, on the uphill road (c) side view, on the downhill.

#### **5** Laboratory Tests and Results

The CTUbike bicycle was constructed at Chienkuo Technology University, and it would be used as the experimental rig in this study. In order to enhance system's adaptive capability, the а linear potentiometer was mounted the head tube. Almost there is no any variation if a bike motion viewed from the frontal plane; therefore, the biker posture control would be especially concentrated on the sagittal plane here. Fig. 12(a) showed the practical measuring mechanism of the inclination angle of road and Fig. 12(b) showed that saddle driving mechanism based on dc servo motor for regulating the biker posture.





#### **5.1 Simulation Results**

The dc-motor dynamic motion model was expressed in (14). Related parameters for a dc motor electrical and mechanical model as listed in Table 1. If the bicycles ride on a sloping road condition occurred, especially like mountain ride, the bicycle might fall down due to the COG position of the whole bicycle system was out of its safe area. Since the inertia moment for the lower wheel of the bicycle was less, thus the bicycle was easy to fall down. To make use of dynamically changing the biker upper body posture or rotating the inclined angle of saddle, the COG position of the bicycle system was shifted and the system stability was improved greatly.

Table 1. DC motor electrical specifications.

Parameters	Symbol	Unit	Data
Dc-motor	$J_m$	$Kg - m^2$	0.00025
inertia		0	
Dc-motor	$B_m$	Kg - m - sec	0.00638
viscous friction			
coefficient			
Torsional spring	K,	Kg - m / rad	32.22
constant	L	C	
Load inertia	$J_L$	$Kg - m^2$	0.00192
DC-motor	K	$K\sigma - m/A$	0.02
torque constant	$\mathbf{n}_t$	118 11/11	0.02
Back-emf	Κ	V / rad./ sec	0.15
constant	е		
DC-motor	л	0	1.40
resistance	$R_a$	Ω	1.42
DC-motor	$L_{*}$	mH	1.17
inductance	a		
Gear ratio	n		1:100



Fig. 13. Sketch of a calculation flow chart of the hysteresis controller.

The feasibility and performance of the proposed control unit was verified by observing the step response. By using the proposed control strategy that was described in section 4, a hysteresis controller was used and assumed that upper and lower limit voltage error was 1 V and 0 V, respectively. A detailed calculation flow chart of the controller was diagrammed in Fig. 13. The step response of dc motor used in this study was obtained by means of Matlab/Simulink simulation software and displayed in Fig. 14.



Fig. 14. In case of only the saddle acted as load, the step response of dc motor control.

### **5.2 Experimental Results**

In the experiments, a biker rode the bicycle on an ascending road and on a descending road associated with an inclination angle. The experimental bicycle when it was driven on these special terrain conditions were successfully recorded on film. Fig. 15 displayed a sequence of three pictures of the experimental bicycle when it was driven on an ascending road, and with a negative inclination angle 30°. Fig. 16 showed a sequence of three pictures of the experimental bicycle when it was driven on a descending road, and with a negative inclination angle 30°.



Fig. 15. Photographs, on an ascending road.



Fig. 16. Photographs, on a descending road.

#### **6** Conclusion

When a bicycle was driven on a sloping road, not only the biker was easily felt fatigue and fall down since the COG position out of safe area, but also resulted in wasting much more power energy. The effects of the COG position moved away the center of contact line was unstable for a bicycle ride, especially mountain ride. Because of the equivalent inertia moment with respect to the lower wheel of the bicycle was decreased when driven on a sloping road. In this paper, a novel simple control system was proposed based on a sensory system for attempting to overcome those issues. By changing biker posture through driving the saddle forward or backward, the stability of the bicycle could be improved greatly. The results caused by the simulation and experiments could validate the proposed control strategy was feasible and useful. The proposed control approach not only is inexpensive but also easily retrofitted into existing bicycles. The technique presented in this paper should be helpful in designing the new mechanism and analyzing the dynamic behavior of an electric bicycle. Additionally, if the intelligent control approaches, such as fuzzy logic control or genetic algorithm are used, hence the system performance, in general, may further be improved.

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