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Dikdo Yuswantoro | Oskar Natan | Achmad Novi Angga | Agus Indra Gunawan | Taufiqurrahman | Bima Sena Bayu Dewantara | Muhammad Andi Kurniawan
2018 International Electronics Symposium on Engineering Technology and Applications (IES-ETA)
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Vein Visualization System Using Camera and Projector Based on Distance Sensor
I Putu Adi Surya Gunawan ; Riyanto Sigit ; Agus Indra Gunawan
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Abstract (1544 Kb)

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Abstract (1571 Kb)

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Nurul Hasanah ; Ali Husein Alasiry ; Bambang Sumantri
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Nurul Hasanah | Ali Husein Alasiry | Bambang Sumantri
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eROV: Preliminary Design of 5 DOF ROV using 6 Thrusters Configuration

Eko Henfri Binugroho ; Raden Sanggar Dewanto ; Dadet Pramadihanto
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Implementation of Balance Recovery by Slight Movement in Humanoid Robot Soccer

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***Abstract*— This paper investigates balancing control of a humanoid robot in soccer application. Many works have been developed to solve balancing control using specific body parts movements while in a standing position. While for small disturbance have shown well, but for quite large disturbance has limited performance. In this paper, we focus on using the slight movement of a robot when quite large disturbance is applied. The robot slightly moves its position to the same direction of the disturbance. Slightly moves of the robot seems more natural with how human perform balancing when receive quite large disturbance. We implement this on our humanoid robot soccer platform. This method is to adjust the step position of the humanoid robot's leg when getting external perturbation to remain the robot in a standing condition. By reprocessing the inverted pendulum control formula, we get the relation between the angular acceleration and the step that the robot should perform. Experiments show that with this strategy our robot platform can prevent itself from falling as twice as better than before. Our method has been successfully applied in the real humanoid robot for robot soccer competition and achieve a remarkable result.**

Keywords*— Balance recovery, slight movement strategy, humanoid robot, inverted pendulum.

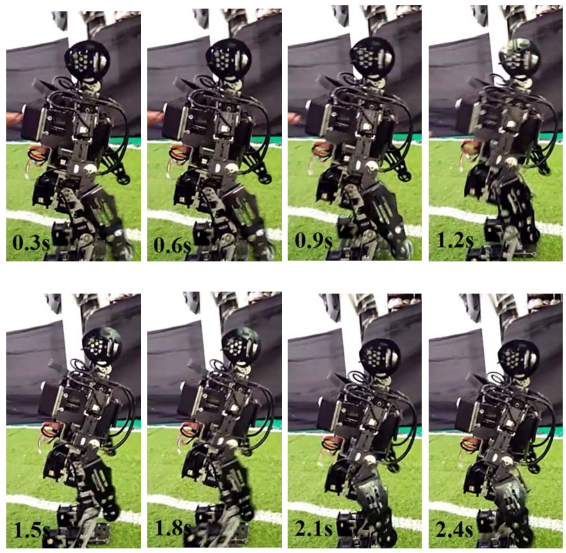

Fig. 1. Humanoid robot slightly moves its position to the same direction of disturbance. A disturbance is applied by pushing the robot with a finger (top-left), and the robot moves forward for balancing (elapsed time is shown at the bottom-left on each image).

I. INTRODUCTION

In the development of a humanoid robot, researchers are competing to find a way to make humanoid robots like humans. Similarly, humanoid robots are devoted to playing soccer, so the ability to recognize objects, kicking, walking, and waking up from the fall should be implanted in the robot. In previous studies, our humanoid robot "EROS", has undergone many developments in the method and control of walking. In the case of walking, the angular speed control has been successfully implemented along with the joint trajectory control [1,2], further optimization has also been carried out by controlling acceleration and deceleration which makes the robot more stable when moving towards maximum speed [3]. The addition of optimization during landing has also been applied to reduce the risk of servo motor damage to the robot [4]. In the case of kicking motion has also been optimized by using joint trajectory controller [5].

Notable works on humanoid robot balancing control employ certain body parts while maintaining robot balance. For example, works by [7,8], torque motor was controlled using PD based on the robot's ankle. The result seems to cause oscillation due to robustness issue. The work by [9] develops Cart-Table Model for designing model predictive control. In the work, the center of mass was used as input parameters for model predictive control's cost function. In [10], capture point was introduced as input feedback parameters to the model predictive control cost function, with the aims to improve the robustness of the controller. The capture point is the location where the center of pressure should arrive to recover balance after disturbances. In general, model predictive control is used to improved robustness by tuning cost function.

Other body parts balancing control strategies such as by moving robot's hip have been done by [11-13]. Generally, the works use flywheel torque, a center of pressure as a control variable to design the controller. Basically, by pulling the center of pressure position back to the support part by rotating hip, then use ankle to restore the balance. Proportional Differential (PD) based controller was employed by [7,8] where various disturbances direction had been tested.

Moreover, the work [15] uses the optimal trajectory library and local optimization control methods to realize the standing balance control. In this case, global optimization could be used

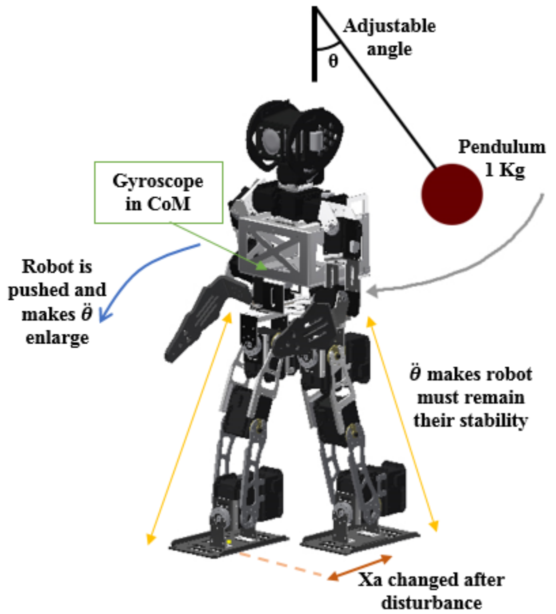

Fig. 2. Overall overview of our system. When a disturbance is applied, the robot performs balancing by moving slightly to the same direction of the disturbance using gyroscope sensor.

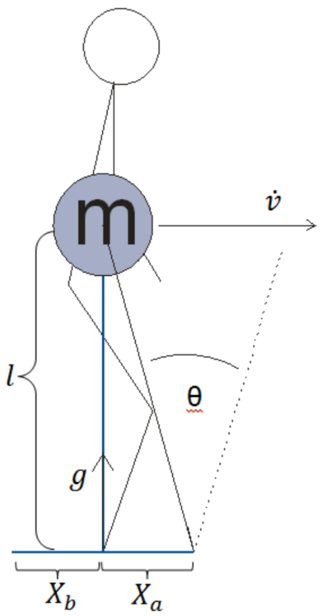

Fig. 3. Humanoid robot diagram based on Linear Inverted Pendulum Model (LIPM) [2]

[16] combined with visual servoing technique [18]. Literature [14] discussed the balance control algorithms under continuous and constant disturbance. As such schemes require the participation of trajectory library, the controller must design the trajectory library generation algorithms, which directly affects the effect of balance control.

In this paper, a balance controller of a humanoid robot is further improved especially when quite large disturbance is applied, as shown in Figure 1. This for example, when other robots collide with our robot. Our strategy uses the slight movement of robot position to maintain balance while in standing position. Note that, the employed strategy is more natural as a human when receiving quite a large disturbance. Human tends to move in the same direction when receives such a disturbance. We model the robot as an inverted pendulum then perform balance controller. From the results of some of these studies, EROS robots have been able to walk and kick quite robust on the field of synthetic grass at a certain speed. Experiments show encouraging result, this balancing strategy has been successfully implemented in the real robot and successfully achieve remarkable result in soccer game.

II. Methodology

Overall system is shown in Figure 2. On the EROS robot had the ability to balance themselves with linear inverted pendulum modeling (LIPM) [2]. The robot will remain in a standing condition and a balanced condition when the center of gravity (CoG) of the robot is still in the Support Polygon Area. The CoG is the midpoint between the center of pressure (CoP) when the robot stands with Double Support Phase (DSP) and become the center of pressure during Single Support Phase (SSP). While the Support Polygon Area (SPA) is an area where the robot can still balance itself when the center of gravity is still inside that.

When the robot is disturbed from the outside, the CoP and the CoG on the robot changes and allows its position to be out of the SPA. When the CoG lies outside of the SPA, the humanoid robot is in a very unbalanced state and allows it to fall. Slight movement strategy that we apply is to keep the robot balance when the CoG is at the outer point of SPA.

In related research, Slight movement strategy has been applied in simulations with a combination of hip, ankle, and stepping strategy by Z. Aftab, et al [6]. In this study requires a sensor to determine the CoP on the palm of the robot as part of the existing formula. Here, we made other ways to implement the strategy with the same algorithm. We use angular and linear acceleration sensors as input from the slight movement strategy that we apply. The value of the angular and linear acceleration is converted through the fuzzy controller and form a new trajectory point for the robot footsteps.

Reconsidering the LIPM that have been applied to the EROS robot when running [2], it produces an acceleration $\dot{v}$. At the inverted pendulum angle from the vertical direction, it produces angular acceleration,

$$\ddot{\theta}_g = (g/L)\sin\theta \qquad (1)$$

Where g is a gravitational acceleration. The acceleration of the robot's movement produces

$$\ddot{\theta}_z = -(\dot{v}/L)\cos\theta \qquad (2)$$

Where $L = \sqrt{l^2 + {X_a}^2}$. We can generate the transfer function *G(s)*, as follows :

$$\ddot{\theta} = \ddot{\theta}_g + \ddot{\theta}_z \qquad (3)$$

$$\ddot{\theta} = (g/L)\sin\theta - (\dot{v}/L)\cos\theta \qquad (4)$$

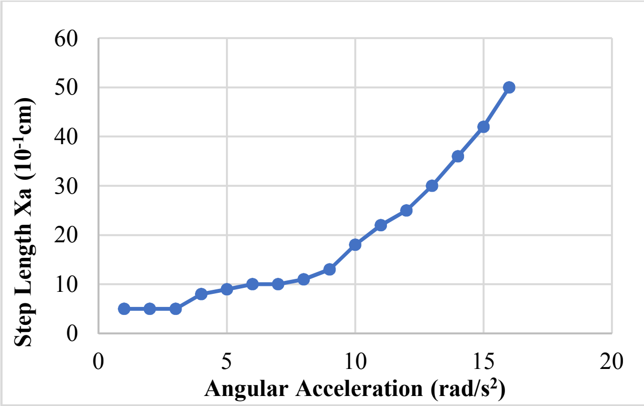

Fig. 4. Angular Acceleration and Step Length relation graph

$$L\ddot{\theta} - g\theta = -\dot{v} \tag{5}$$

$$G(s) = \frac{\theta(s)}{v(s)} = \frac{-s}{Ls^2 - g} = \frac{-s/g}{(\tau_L s+1)(\tau_L s+1)} \tag{6}$$

Where time constant τ_L defined as,

$$\tau_L = \sqrt{L/g} \tag{7}$$

From the modeling in Figure 3 and the transfer function, we obtained the pendulum angle θ and controlled to remain its balance, it makes $\theta < \tan^{-1}(X_a/l)$.

Because in this context we limit research only to walking in current place, it makes the value of X_a is 0. So the value of θ produces about 0 degrees. This makes only a little external perturbation make the robot become unstable and fall.

From that equation, we compare the angular acceleration and the step that must be generated when the robot gets external perturbation, with a constant l value of 210mm as the height of robot's legs when the robot stands. We obtained Figure 4 which is graph of result of relationship $\ddot{\theta}$ and X_a.

From the graph in Figure 4, we know that step length is directly proportional with angular acceleration. The greater the value of angular acceleration, the greater step length that must be generated also. Hence, we divide some points of the angular acceleration value as some points of step length to simplify the experiment. A value mapping for each angular acceleration value is converted to trajectory value to change the length of steps performed by the robot.

Table 1. Condition that generated from Figure 4 graph.

Condition	*Generated Step Length Xa (10^{-1}cm)*	*Angular Acceleration (rad/s^2)*	*Number of Steps*
1	0-10	0-5	0
2	10-20	5-10	2
3	20-40	10-15	4
4	40-Max	>15	6

As in Figure 5, the walking pattern generation that had been generated by default pose based CoG and gyroscope as an angular acceleration sensor as an input of stepping strategy. Its value will affect the next function and makes motion robot changed when the external perturbation applied. With this algorithm, we can get a new walking pattern from Slight Movement Strategy and use Inverse Kinematic to get the angle of every joint in robot's leg.

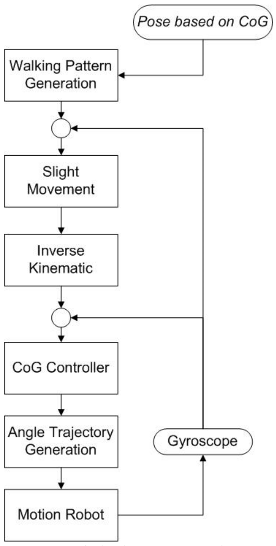

Fig. 5. Humanoid robot control design system in generating robot motion

Algorithm 1 Slight Movement Strategy

Input : Walking Pattern *(X, Y, Z, θ)*, Gyroscope Sensor *($\ddot{\theta}$)*
Output : Robot Movement

```
loop
  WP←WalkingPattern(X,Y,Z,H)
  if Single-Support then
    for i = 1, N_Step do
      WP←SlightMovementStrategy(WP,θ̈)
    end for
  end if
  InversKinematics(WP)
end loop
```

In the algorithm, we have input X, Y, Z, θ as a cartesian and an angle of the end of effector (EoE) on the robot's toe. A step is counting in every SSP condition to avoid mistakes in the control method. In every step, we generate a new walking pattern that combines current walking pattern and the value of angular acceleration sensor. We use condition in Table 1 to generate a new walking pattern based on the value of sensor.

III. Experiments

In this experiment, we divide into 4 conditions that occur in the robot to get a well-analyzed result that is, A) The robot walks in place without disturbance and without slight movement strategy, B) The robot walks in place without disturbance and with slight movement strategy, C) The robot walks in place with disturbance and without slight movement strategy, and D) The robot walks in place with disturbance and with slight movement strategy. The disturbance is given in the form of encouragement with 1 kg mass of pendulum and adjusted angle of pendulum. The pendulum released from back of the robot in certain angle and hit the robot like in Figure 2. The data that we put in the graph is angular and linear on x and y axis.

The color of cyan shows the angular acceleration of the x-axis. The light green color shows the angular acceleration of the y-axis. The red color represents the linear acceleration of the x-axis and the blue color represents the linear acceleration of the y-axis.

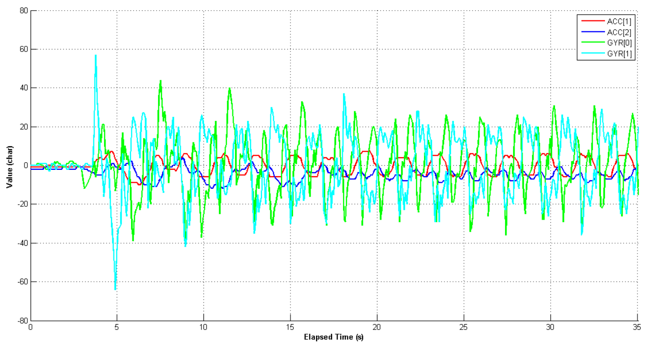

Fig. 6. x-axis and y-axis graph without disturbance and without slight movement strategy

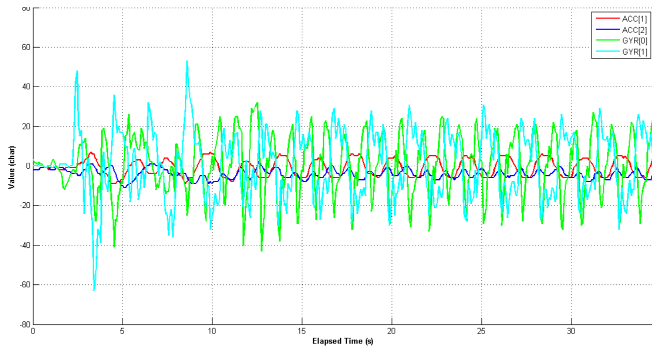

Fig. 7. x-axis and y-axis graph without disturbance and with slight movement strategy

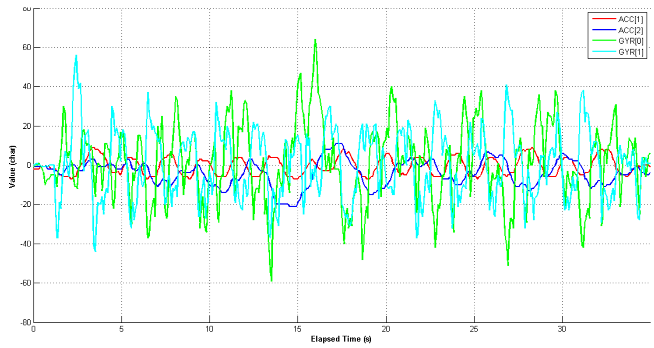

Fig. 8. x-axis and y-axis graph with disturbance and without slight movement strategy

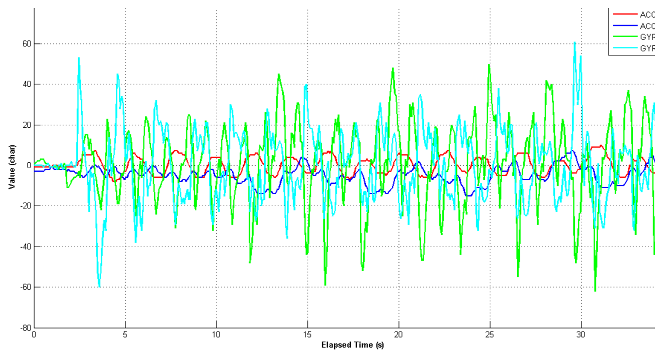

Fig. 9. x-axis and y-axis graph with disturbance and with slight movement strategy

A. The robot walks in place without disturbance and without slight movement strategy

When the robot walking in place, the vibration of the robot tends to stable and the graph of angular acceleration tends to repeat itself (Figure 6) which indicates that there is no external disturbance. The vibration in the graph caused by trajectory walking of the robot when switching from SSP to DSP and vice versa.

B. The robot walks in place without disturbance and with slight movement strategy

The same graph we get for robots using slight movement strategy without disturbance. Angular acceleration graphs tend to repeatedly signify a stable system while performing motion walking in place as shown in Figure 7.

C. The robot walks in place with disturbance and without slight movement strategy

In this experiment (Figure 8), the disturbance is applied. It can be seen on the graph that the change in the value of angular acceleration and linear acceleration is greater than without disturbance (Figure 6 and Figure 7) and the graph tends to not be patterned because the robot tries to defend itself in a fixed position by not using slight movement strategy. The movement to defend itself without slight movement strategy makes it unstable and falls down.

D. The robot walks in place with disturbance and with slight movement strategy

Unlike the previous charts, graphs on robots using slight movement strategy when it gets disturbance tend to vibrate more. This is because the robot does not maintain the position but moves the position following the direction of the force by changing its steps. As a result, the robot goes forward which makes the angular acceleration value even greater, as shown in Figure 9.

For more significant results, we conducted several experiments to compare the use of slight movement strategy and not on robots that were in a condition of getting disturbance. We applied a swinging pendulum in angle 30° also by using 1 kg as the mass of pendulum. From these experiments we get the following results.

Table 2. Experiment using slight movement strategy when the robot gets disturbance from pendulum in angle of 30°.

Experiment	with *Slight Movement*	without *Slight Movement*
1	Forward unstable	Fall
2	Forward unstable	Fall
3	Forward stable	Fall
4	Fall	Fall
5	Forward unstable	unstable
6	Forward unstable	unstable
7	Forward unstable	Fall
8	Fall	Fall
9	Fall	unstable
10	Forward unstable	Fall

Another experiment has done to get a better conclusion. We apply some different forces using pendulum also. We adjust the angle of the pendulum when it released. By adjusting the angle and a fixed mass of the pendulum, we get a different force that will be applied to the robot. From these experiments we get the following results.

From the result in Table 2 and 3, we know that using Slight Movement, robot can prevent itself from falling although the robot is in unstable condition when trying to maintain its stability. The robot can prevent from falling twice than not using Slight Movement and the robot can prevent from falling when greater force is applied marked by the value of the pendulum's angle.

Table 3. Experiment using slight movement strategy and using different angle in releasing pendulum.

Experiment	Angle (°)	with Slight Movement	without Slight Movement
1	5	Stable	Stable
2	10	Stable	Stable
3	15	Stable	Stable
4	20	Forward stable	Stable
5	22	Forward stable	Unstable
6	24	Forward stable	Unstable
7	26	Forward unstable	Unstable
8	28	Forward unstable	Fall
9	30	Forward unstable	Fall
10	32	Forward unstable	Fall
11	34	Fall	Fall
12	36	Fall	Fall

IV. CONCLUSION

In this paper, implementation of balance controller using the slight movement strategy has been developed to encounter quite a large disturbance such as collision with other robots in a soccer game. Differing from other works that move certain robot body parts to perform balancing, our system seems more natural with the way human perform balancing when a quite a large disturbance is applied. The controller is modeled using an inverted pendulum and applied control strategy based on it. This system has been successfully implemented in the real robots which we developed in our platform (EROS) and achieve a remarkable result in the soccer game.

V. FUTURE WORKS

It is interesting to do performing the balancing strategy by adding pressure sensors on robot's feet. With the purpose that the robot knows and predicts how much the force on each foot, thus estimating how many steps are needed for certain disturbance force. Then the recent deep learning methods [17,19] are interesting to be explored.

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