Influence of Upper Body with Dual Arms on Posture Control of Independently Driven Quadruped Crawler Robot

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Abstract

Independently Driven Quadruped Crawler Robot(IDQCR) can rescue survivors rapidly in case of disaster situations. In order to prevent rollover, the IDQCR must level out the operator cabin to overcome rough terrain and do posture control when gripper is carrying heavy things of the robot. In this paper, we define a mathematical model based on differential kinematics for posture control and discuss the influence of the posture control to upper body of IDQCR on. In order to verify the proposed mathematical model, we simulated with DAFUL and MATLAB/Simulink, which can analyze dynamics.

Keywords –

Rollover; Influence of Upper Body; Independently Driven Quadruped Crawler; Posture Control; Disaster Response Robot; Wheel-legged System;

1 Introduction

Globally, occurrence frequencies of disasters such as conflagration and earthquake are increasing gradually [1]. When huge disasters occur, survivors are possibly under collapsed debris and rescue is not easy when a fire occurs. The existing survivor rescue systems needs plenty of rescue time because of various variables and additional collapse can make the situation worse[2].

For this reason, it is necessary to develop the robot for rescue and the robot must be able to travel on rough terrain. As a requirement of robots for the disaster, the ability to overcome the roughness, ease of operation and promptness must be satisfied.

Firstly, the ability to overcome obstacles allows four independent legs to freely pass obstacles by attaching a crawler that can easily overcome obstacles.

Secondly, the ease of operation is that the existing excavators have to control the four legs directly by the driver, but IDQCR is easy to control the joints and crawler speed of each leg automatically according to the terrain.

Thirdly, in the event of a disaster such as a large-scale earthquake or a fire, other heavy equipment or vehicles can't be operated properly due to collapsed debris, but the IDQCR can be quickly put into the field.

Various systems for safe operation for preventing rollover in the disaster environment have been proposed [3-6]. The DARPA Robotics Challenge, the symposium to perform missions in disaster situations, is being studied mainly in humanoid robots [7]. In addition, control methods for improving the driving systems of military robots have been studied, but research on the control techniques applied to the driving systems of large robots such as IDQCR has not been conducted [8].

Previous studies have concentrated on posture control considering only the lower body of the robot [9]. In this paper, we study the effect of the robot on the posture control by integrating the lower body and the upper body of the robot when overcoming the rough terrain. We propose a mathematical model for the posture control of the IDQCR driving system and verify the results by simulation considering the weight of the robot upper body. We entered the weight for each part of the upper body and tried to demonstrate the posture control by simulating the pose of stretching the two arms, which are the worst situation.

2 Introduction for Posture Control System of Disaster Response Robot

Fig. 1 shows the appearance of Independently Driven Quadruped Crawler Robot (IDQCR).

Four independent leg mechanisms can make the operator cabin horizontal when driving or working on rough terrain, with a crawler to easily overcome obstacles.

The legs mechanism independently drives the four hydraulic cylinders attached to the chassis to implement the up and down movements of the robot. The four hydraulic cylinders attached to the inside of the legs mechanism adjust the distance between the legs.

Fig. 2, the four hydraulic cylinders attached to the chassis are related to the driving system and show the relation with the posture control.

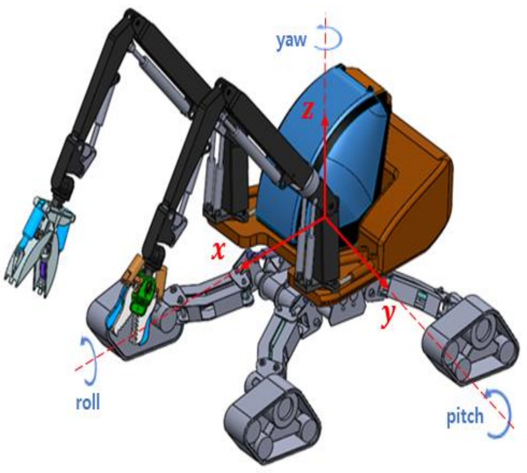

Figure 1. Independently Driven Quadruped Crawler Robot with integrated lower and upper body

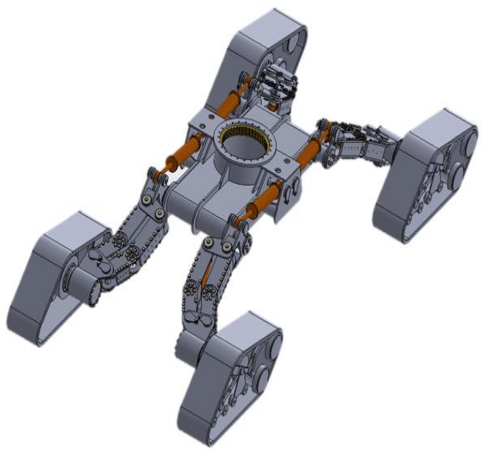

Figure 2. Independently Driven Quadruped Crawler system for posture control

The posture control of the driving system is related to up and down movement, roll and pitch motion of the robot. the posture control of the working system uses the four hydraulic cylinders inside the leg mechanism to expand the area of the support polygon [10].

The upper part of the robot consists of cabin, chassis, arm, 8 hydraulic cylinders and 2 grippers. The eight hydraulic cylinders are designed to have four degrees of freedom for each arm of IDQCR.

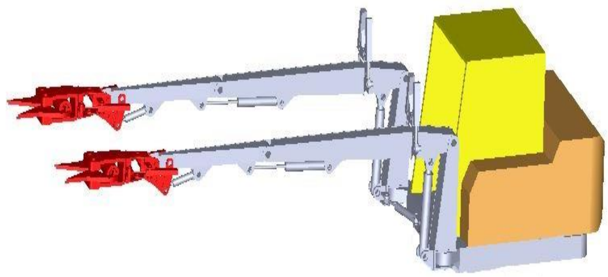

Figure 3. The worst posture of upper body posture of IDQCR

Fig. 3, the most worst posture of the upper body posture of IDQCR is the posture in which the two arms are stretched straight. If there is no rollover in that posture, there is no rollover.

3 Posture Control of Disaster Response Robot

3.1 Coordinate Frame for Robot

Prior to setting differential kinematics model, the setting of coordinate system must be preceded. Figure. 4 shows the schematic diagram of the system. {A} is global coordinate. The origin of {B} is located in the centre of mass of IDQCR in the driving system. z_B is an unit vector in the direction of outer product with y_B and x_B. y_B is an unit vector in the left direction of the robot and x_B is an unit vector in the front direction of the robot.

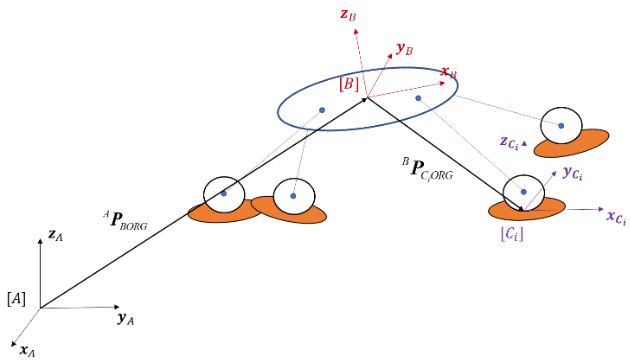

Figure 4. The schematic diagram of the system

3.2 Differential Kinematic Model of Robot

With respect to the coordinate system{A}, the velocity of the origin of frame $\{C_i\}$ is denoted by ${}^AV_{C_iORG}$ and can be obtained by the following equation (1).

$$ {}^AV_{C_iORG} = {}^AV_{BORG} + {}^A\Omega_B \times {}^A_BR\,{}^BP_{C_iORG} + {}^A_BR\,{}^BV_{C_iORG} \tag{1} $$

${}^AV_{BORG}$ is a linear velocity of the origin of {B} relative to frame {A} and ${}^A\Omega_B$ is the angular velocity of frame {B} relative to frame {A}. ${}^A_BR$ is the rotation matrix of {B} relative to frame {A}. ${}^BP_{C_iORG}$ is the position vector of the coordinate system $\{C_i\}$ relative to frame {B}. ${}^BV_{C_iORG}$ is linear velocity of the origin of frame $\{C_i\}$ relative to frame {B}. ${}^BV_{C_iORG}$ can be expressed as the product of the Jacobian matrix J_i and the joint angular velocity of the leg and the sprocket $\dot{q}_i = [\dot{\alpha}_i\ \dot{\beta}_i]$ of the crawler. Assuming that there is no slip between the crawler and the ground, ${}^AV_{C_iORG} = 0$ and then equation (2) can be derived.

$$ {}^{C_i}({}^AV_{C_iORG}) = L_i\dot{X} + J_i^*\dot{q}_i = 0 \tag{2} $$

3.3 Jacobian Matrix

$J_i^*\dot{q}_i$ of equation (2) is divided into two velocity components as equation (3).

$$ J_i^*\dot{q}_i = {}^{C_i}({}^BV_{\dot{\alpha}_i}) + {}^{C_i}({}^BV_{\dot{\beta}_i}) \tag{3} $$

${}^BV_{\dot{\alpha}_i}$ is a component related to the joint velocity $\dot{\alpha}_i$ of ${}^BV_{C_iORG}$ and ${}^BV_{\dot{\beta}_i}$ is a component related to the joint angular velocity $\dot{\beta}_i$ of crawler sprocket of ${}^BV_{C_iORG}$. ${}^{C_i}({}^BV_{\dot{\alpha}_i})$ and ${}^{C_i}({}^BV_{\dot{\beta}_i})$ can be obtained by the following equations (4) and (5).

$$ J_i^*\dot{q}_i = {}^{C_i}_BR\, J_{\dot{\alpha}_i}(\dot{\alpha}_i) + \dot{\beta}_i(-r\ 0\ 0)^T \tag{4} $$

$$ J_i^*\dot{q}_i = [{}^{C_i}_BR \begin{bmatrix} -lsin\alpha_i \\ 0 \\ -lcos\alpha_i \end{bmatrix} \begin{bmatrix} -r \\ 0 \\ 0 \end{bmatrix}] \begin{bmatrix} \dot{\alpha}_i \\ \dot{\beta}_i \end{bmatrix} \tag{5} $$

$J_{\dot{\alpha}_i}$ is a Jacobian matrix of ${}^BV_{\dot{\alpha}_i}$, r is a radius of sprocket and l is the link parameter between the joint and the crawler sprocket.

3.4 Domain between the Joint and the Crawler Sprocket.

$\dot{X} = [{}^B({}^AV_{BORG})^T\ \ {}^B({}^A\Omega_B)^T]^T$ is a 6×1 matrix that consists of the linear velocity vector and angular velocity vector. Let ${}^B({}^AV_{BORG}) = [v_x\ v_y\ v_z]^T$ and ${}^B({}^A\Omega_B) = [w_x\ w_y\ w_z]^T$.

Then, $\dot{X} = [v_x\ v_y\ v_z\ w_x\ w_y\ w_z]^T$. We need to change the control parameter domain from $\dot{X} = [v_x\ v_y\ v_z\ w_x\ w_y\ w_z]^T$ to $\dot{H} = [v_x\ v_y\ \dot{z}_{avg}\ \dot{\phi}\ \dot{\theta}\ \dot{\psi}]^T$. Where $z_{avg} = \sum_i^k z_i$. z_i is value of ${}^BP_{C_iORG}$ in z_B direction and k is the number of legs. $\dot{\phi}$ is the roll angle rate, $\dot{\theta}$ is the pitch angle rate and $\dot{\psi}$ is the yaw angle rate. Figure. 5 is showing overall notation and coordinate.

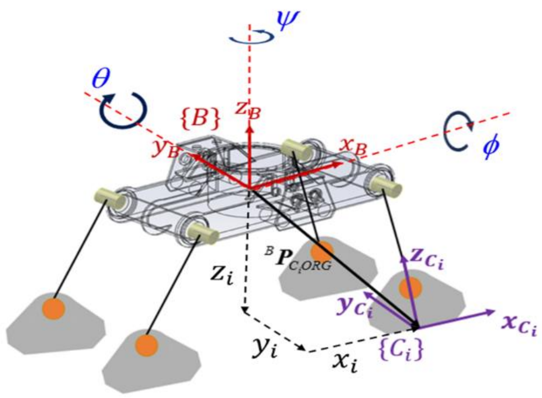

Figure 5. The description of the mentioned notation

A relationship between v_z and $\dot{z}_{avg}$ is equation (6).

$$ v_z = -\dot{z}_{avg} + w_y x_{avg} - w_x y_{avg} \tag{6} $$

Where $x_{avg} = \sum_i^k x_i$ and $y_{avg} = \sum_i^k y_i$. x_i and y_i are values of ${}^BP_{C_iORG}$ in x_B and y_B direction respectively. Since we want to control $\phi = 0°$ and $\theta = 0°$. $w_y = \dot{\theta}\cos(\phi) + \dot{\psi}\cos(\theta)\sin(\phi) \cong \dot{\theta}\cos(\phi)$ and $y_{avg} = 0$. Then, the equation (6) can be (7).

$$ v_z \cong -\dot{z}_{avg} + \dot{\theta}\cos(\phi) \tag{7} $$

By using the relationship between Euler angle and angular velocity, 'xyz' transformation, a relationship between $\dot{X}$ and $\dot{H}$ can be derived as (8).

$$\begin{bmatrix} v_x \\ v_y \\ v_z \\ \Omega_x \\ \Omega_y \\ \Omega_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & c_\phi x_{avg} & 0 \\ & & & 1 & 0 & -s_\theta \\ & 0_{3\times 3} & & 0 & c_\theta & c_\theta s_\phi \\ & & & 0 & -s_\theta & c_\theta c_\phi \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ \dot{z}_{avg} \\ \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \quad (8)$$

Resultingly, rate of crawler and body velocity, in other words relation between task and joint space in this machine can be derived like (9).

$$\dot{q} = -(J^*)^+ \mathrm{LU}\dot{H} \quad (9)$$

U is 6 by 6 matrix in (8). By using this equation (9), CLIK (Closed Loop Inverse Kinematics) algorithm was applied to method about rollover prevent and simulation used it.

4 Influence of Upper Body Posture

In the existing lower body posture control algorithm, the weight of the upper body of the IDQCR and the weight of the object gripped by the gripper are not considered. In order to travel while performing work and posture control, it is necessary to consider the result of influence of the upper body posture and to implement an additional rollover prevention algorithm. We can determine the influence on the rollover in several various posture and determine the worst posture.

4.1 When both arms are driven dependently

We divided the cases where two grippers hold one object in two cases.

4.1.1 Case 1

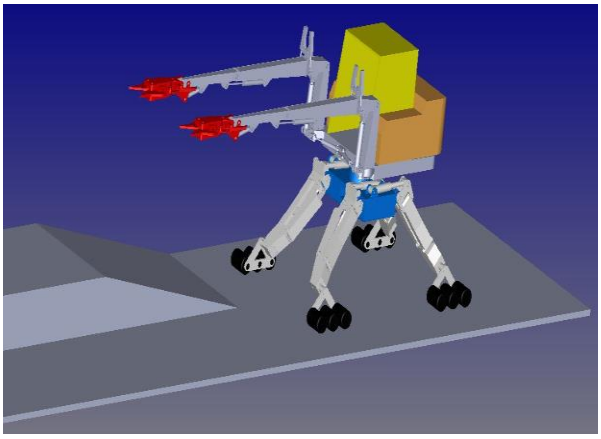

Figure 6. when both arms are stretched straight in the direction of robot's movement

The most basic posture like figure. 6 is when the two arms stretched straight in the direction of the robot's motion. Figure. 7 shows the case where the upper body is rotated 90 degree in the Yaw direction.

4.1.2 Case 2

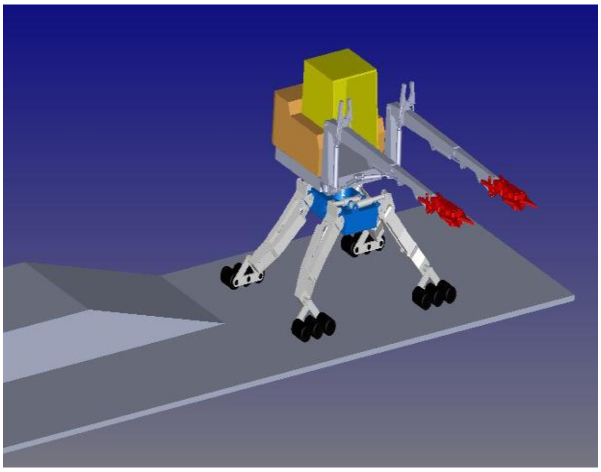

Figure 7. when the upper body is rotated 90° in the Yaw direction.

4.2 When both arms are driven independently

4.2.1 Case 3

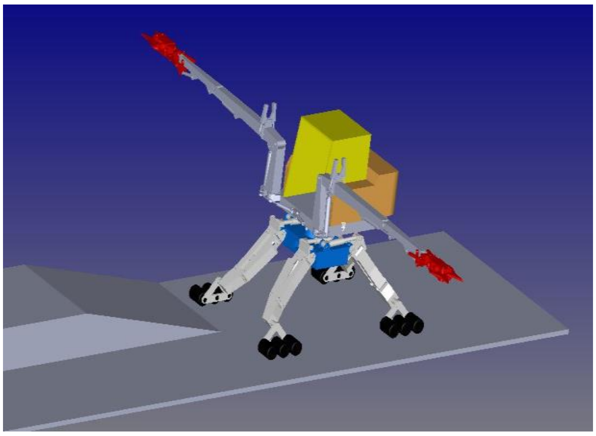

Figure 8. Two grippers hold two objects each

Figure. 8 shows that each grippers hold objects with different weight.

5 Simulation Analysis and Results

In order to verify the proposed mathematical model, we simulated with DAFUL and MATLAB/Simulink, which can analyze dynamics [11]. The simulation conditions are shown in Figure 9, Figure 10, the performance of the proposed model was verified by setting the roll angle to 35 ° and the pitch angle to 25 °.

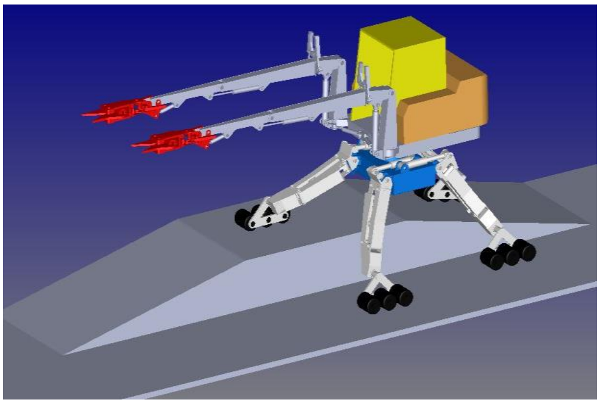

Figure 9. Simulation Condition of Roll angle (35°)

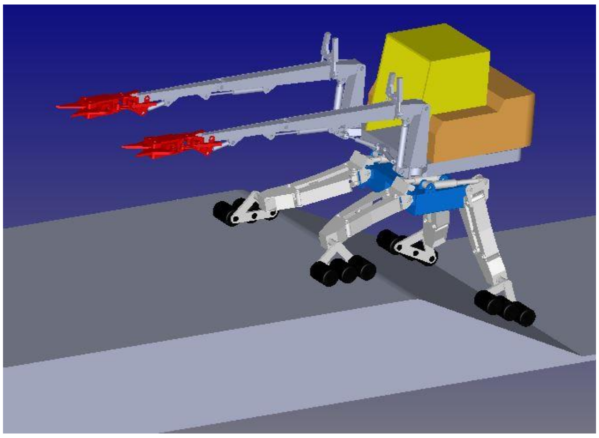

Figure 10. Simulation Condition of Pitch angle (25°)

5.1 Simulation of Roll and Pitch angle

Figure 11 and Figure 12 is the result of the roll angle and pitch angle considering the weight of the upper body of the robot. Figure 11 shows that the robot cannot be rolled over but the cabin is not perfectly horizontal, Figure 12 shows the result of rolled over in the ground-falling period while maintaining the roll angle to 0° in the ground-rising period. In the roll and pitch values analyzed from the mathematical model proposed above, the posture control is perfect for the robot considering only the lower body, but when the robot integrated with the upper body, the robot becomes unstable.

In figure 13 We could confirm the rollover result when simulating the grippers with more than 1.4t objects. An algorithm is needed to find a stable posture when the robot reaches the rollover threshold.

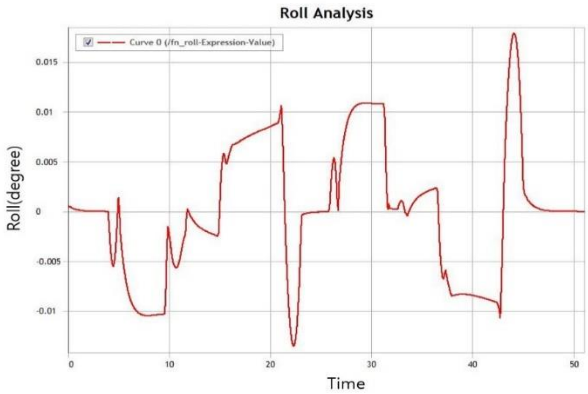

Figure 11. Result of Roll angle

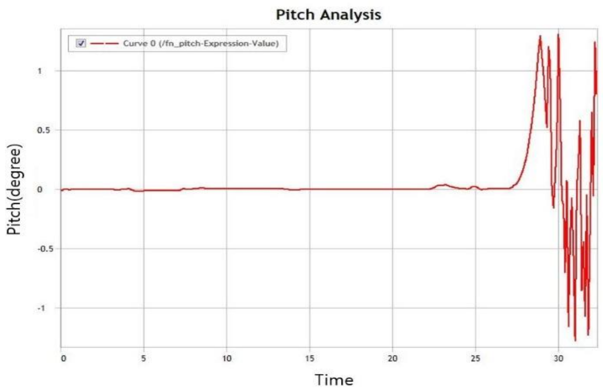

Figure 12. Result of Pitch angle

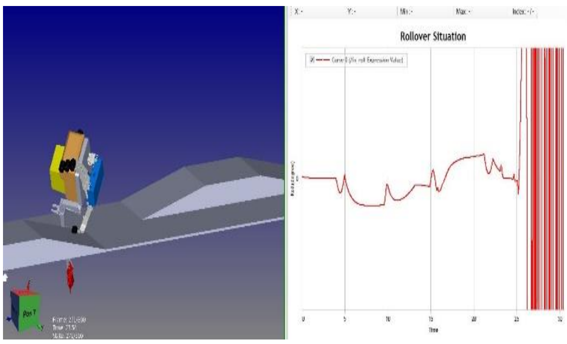

Figure 13. Result of Rollover situation

5.2 Simulation Result of Various Posture

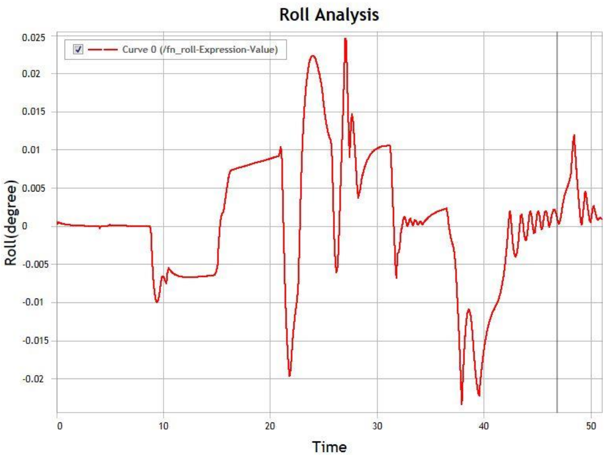

Figure 14. Result of Case 3

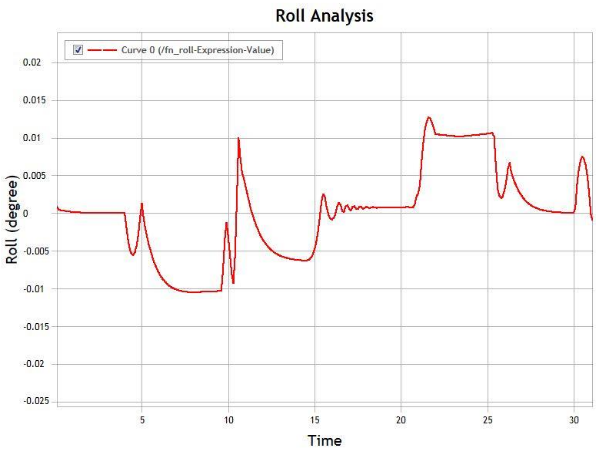

Figure 15. Result of Case 2

Figure 14 is a graph showing the results of Case 3, and Figure 15 is a graph showing the results of Case 2. The graphs in Figures 14 and 15 show that the Roll angle is shaking a lot and we can confirm unstable results.

6 Conclusion and Future Work

In this paper, we propose a mathematical model for the posture control of the IDQCR driving system.

In addition to, the results were confirmed and verified by simulation considering the weight of the upper body of the robot. The proposed mathematical model confirmed that the cabin maintains the horizontal position but does not achieve perfect posture control. It has been confirmed that the rollover occurs when the gripper is weighed more than 1.4t and we confirmed unstable results when simulate various posture. In order to compensate the rollover, an additional algorithm is need to prevent rollover control as well as a posture control algorithm when the overturn limit occurs.

7 Acknowledgement

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