A study on the Modeling of Independently Driven Quadruped Crawler System for Posture Control of Special Purpose Machine for Disaster Response

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Abstract

The crawler-leg mobile system is a sub-mechanism of special purpose machines for the early stage rescue and reconstruction in disaster. This system plays a role in controlling the posture to prevent rollover when the special purpose machine is running on rough terrain. In this paper, a mechanism is introduced for posture control of a crawler-leg mobile system and coordinates for mathematical model is define. Using defined coordinates, a mathematical model based on differential kinematics is proposed for posture control system. The validity of the mathematical model is verified by comparing the results of the proposed mathematical model and the multi body dynamics simulation model. And a mathematical model is proposed for posture control of the crawler-leg mobile system.

Keywords –

Independently Driven Quadruped Crawler; Posture Control; Special Purpose Machine; System Modeling; Crawler-Leg Mobile System

Introduction

Globally, occurrence frequencies of disasters such as conflagration, earthquake are increasing gradually [1].

Due to industrialization and urbanization, the number of large buildings and underground buildings are increasing, and in a major disaster, it can lead to the collapse of buildings and massive casualties. In the event of collapse of building, the rapid rescue of survivors buried in collapsed debris is very important for minimizing the loss of life after the disaster. However, the existing survivor rescue systems rely on rescue personnel. It is not easy to approach the rescuers due to constraints such as secondary collapse. And additional collapse accidents can increase the risk to both rescues and survivors [2].

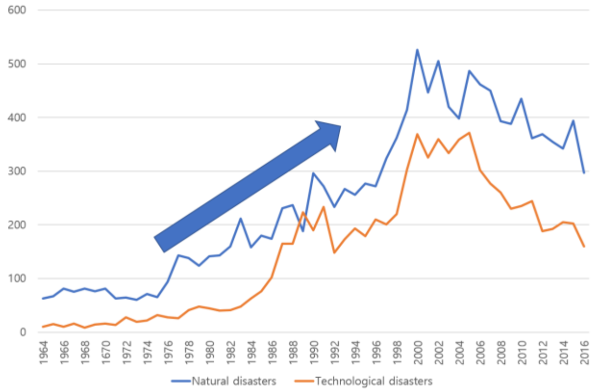

Fig. 1. International disaster trends (1964~2016)

For this reason, it is necessary to develop the equipment for securing access roads, rescue and preventing secondary collapse at disaster sites such as collapses, it is urgent to develop a system capable of traveling on the dangerous road.

Various systems have been proposed for rugged driving in disaster situations. In France, a robot with a combination of legs and wheels for rugged driving has been proposed. After developing a velocity model by analyzing the kinematics of the robot, researches have been carried out to improve the driving stability of the vehicle [3-7]. Nagano and Fujimoto of Yokohama University in Japan proposed an acceleration-based kinematic model for the movement and control of mobile robot combined with bridge and wheel, and developed an algorithm to generate robot control path of Least squares method of solving Singular configuration problem [9]. In addition, a control method to improve the moving performance by controlling the rigidity of the actuator attached to the leg of the compliant wheel-leg robot at the uneven road surface has been studied

[10].

As you saw above, most of the researches to improve the running performance of the rugged area have been focused on robots that light in weight and have a high degree of freedom. However, research on control techniques applied to huge driving systems such as disaster response equipment has not been conducted.

In this paper, I propose a mathematical model for posture control of a crawler-leg driving system. I introduce a disaster response system for mathematical model generation and propose a mathematical model of the crawler-leg system using the differential kinematic method. I compare the proposed mathematical model with the dynamics simulation model to verify the performance of the proposed model.

1. Introduction for Posture Control System of Special Purpose Machine

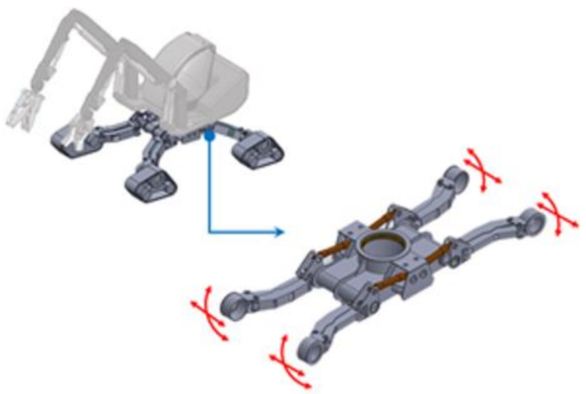

Fig. 2. Special Purpose Machine and posture control system

Fig. 2 is the draft of Special purpose machine. This system has four leg mechanisms to overcome the roughness such as irregular unevenness and attached to the lower part of the legs each can be independently driven crawler. The leg mechanism independently drives the four-posture control hydraulic cylinders mounted on the upperpart to implement the up and down movement of each leg and to drive the hydraulic cylinder acting as an outrigger inside the leg mechanism, do. The posture of the upper body can be controlled by using the up and down movement mechanism of the leg.

The Fig. 3 shows the relationship between the motion of the leg mechanism and the posture control of the traveling system. The independently actuation of the four cylinders mounted on the leg enables three motion.

1. (a) Up and down movement of the upper body
2. (b) Roll motion of the upper body
3. (c) Pitch motion

By driving four lower cylinders, the distance between the left and right legs is extended or reduced as shown in (d), thereby enabling stable support of the upper body, posture control, and movement of the narrow space.

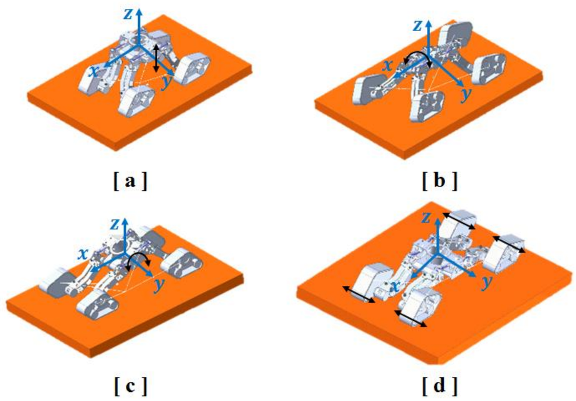

Fig. 3. Analysis of posture control mechanism

2. System Modeling for Posture Control of Special Purpose Machine

In this chapter, I propose differential kinematic model for posture control of special purpose machine.

2.1 Setting Coordinate for posture control modeling

Prior to setting differential kinematic model, the coordinate system setting must be preceded. Fig. 4 shows the schematic diagram of the system. The coordinate {A} is z_A global coordinate. z_A is a unit vector pointing in the opposite direction to the center of the Earth, and the outer product of x_A and y_A with a vector is a horizontal plane. The coordinate {B} is the platform coordinate. The origin of the platform coordinate system {B} is located at the center of gravity of the platform in the running system. x_B is a unit vector in the front direction of the platform, and y_B is a unit vector in the left direction of the platform. z_B is a unit vector in the direction of outer product with x_B and y_B.

Fig. 5 shows the i-th crawler. Assume that the crawler is in contact with the ground, the bottom of the crawler is the contact surface. The coordinate system {C_i} is the coordinate i-th crawler.

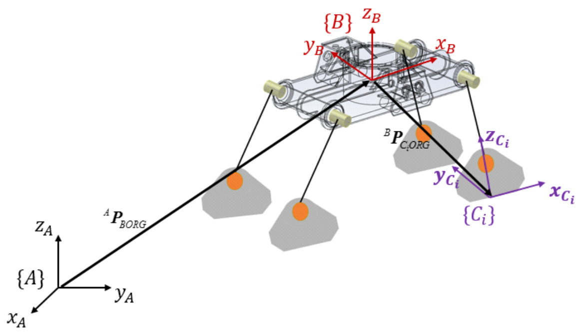

Fig. 4. The schematic diagram of the system

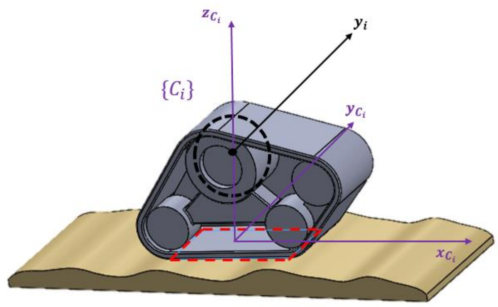

Fig. 5. The i-th crawler and contact plane between crawler and ground

2.2 Posture Control model based on differential kinematics

The origin velocity of { C_i } for the coordinate system {A} is denoted by.

$$ {}^{A}V_{C_iORG} = {}^{A}V_{BORG} + {}^{A}\Omega_B \times {}^{A}_{B}R\,{}^{B}P_{C_iORG} + {}^{A}_{B}R\,{}^{B}V_{C_iORG} \qquad (1) $$

Or

$$ \begin{bmatrix} {}^{A}\dot{x}_{C_iORG} \\ {}^{A}\dot{y}_{C_iORG} \\ {}^{A}\dot{z}_{C_iORG} \end{bmatrix} = \begin{bmatrix} {}^{A}\dot{x}_{BORG} \\ {}^{A}\dot{y}_{BORG} \\ {}^{A}\dot{z}_{BORG} \end{bmatrix} + \begin{bmatrix} {}^{A}\omega_{xB} \\ {}^{A}\omega_{yB} \\ {}^{A}\omega_{zB} \end{bmatrix} \times \begin{bmatrix} x_B \bullet x_A & y_B \bullet x_A & z_B \bullet x_A \\ x_B \bullet y_A & y_B \bullet y_A & z_B \bullet y_A \\ x_B \bullet z_A & y_B \bullet z_A & z_B \bullet z_A \end{bmatrix} \begin{bmatrix} {}^{B}x_{BORG} \\ {}^{B}y_{BORG} \\ {}^{B}z_{BORG} \end{bmatrix} + \begin{bmatrix} x_B \bullet x_A & y_B \bullet x_A & z_B \bullet x_A \\ x_B \bullet y_A & y_B \bullet y_A & z_B \bullet y_A \\ x_B \bullet z_A & y_B \bullet z_A & z_B \bullet z_A \end{bmatrix} \begin{bmatrix} {}^{B}\dot{x}_{C_iORG} \\ {}^{B}\dot{y}_{C_iORG} \\ {}^{B}\dot{z}_{C_iORG} \end{bmatrix} \qquad (2) $$

${}^{A}V_{BORG}$ is the origin velocity of {B} for the coordinate system {A}. ${}^{A}\Omega_B$ is the angular velocity of {B} for {A}. ${}^{A}_{B}R$ is the rotation matrix of {B} for {A}. ${}^{B}P_{C_iORG}$ is the position vector of {C_i} as seen from {B}. ${}^{B}V_{C_iORG}$ is the velocity of origin of {C_i} from {B}.

Multiply ${}^{C_i}_{A}R$ that is a rotation matrix from {A} to {C_i} both sides of equation (1).

$$ {}^{C_i}_{A}R({}^{A}V_{C_iORG}) = {}^{C_i}_{A}R({}^{A}V_{BORG}) - {}^{C_i}_{B}R[S({}^{B}P_{C_iORG})^{B}({}^{A}\Omega_B)] + {}^{C_i}_{B}R\,{}^{B}V_{C_iORG} \qquad (3) $$

The velocity of origin of {C_i} from {B} of equation (3) can be expressed by product of Jacobian matrix J_i and angular velocity of joint in Fig. 6. So, we can get equation (4).

$$ {}^{C_i}_{A}R({}^{A}V_{C_iORG}) = {}^{C_i}_{A}R({}^{A}V_{BORG}) - {}^{C_i}_{B}R[S({}^{B}P_{C_iORG})^{B}({}^{A}\Omega_B)] + {}^{C_i}_{B}RJ_i\dot{q}_i \qquad (4) $$

$$ {}^{C_i}({}^{A}V_{C_iORG}) = L_i\dot{X} + J_i^{*}\dot{q}_i \qquad (5) $$

where
$$ L_i = [{}^{C_i}_{B}R \quad -{}^{C_i}_{B}RS({}^{B}P_{C_iORG})] $$
$$ \dot{X} = [{}^{B}({}^{A}V_{BORG}) \quad {}^{B}({}^{A}\Omega_B)]^T $$
$$ J_i^{*} = {}^{C_i}_{B}RJ_i $$

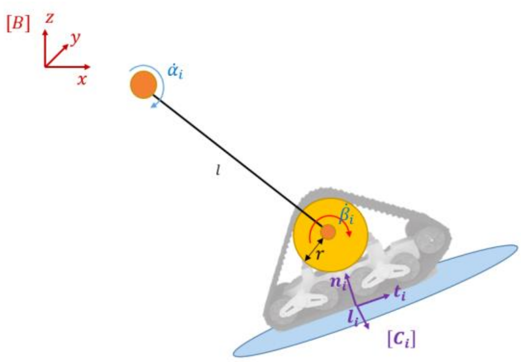

Fig. 6. The schematic diagram of one leg

Assume that there is no slip between crawler and ground surface. Equation (5) changes to equation (6).

$$ L_i\dot{X} + J_i^{*}\dot{q}_i = 0 \qquad (6) $$

Since the motion of each leg is coupled with linear and angular velocity, the whole model of the system is as follows

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{bmatrix} \dot{X} + \begin{bmatrix} J_1^* & & & \\ & J_2^* & & \\ & & J_3^* & \\ & & & J_4^* \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \end{bmatrix} = 0 \qquad (7)$$

2.3 Jacobian Matrix

Second term of equation (6) is divided into two velocity components as follow

$$J_i^* \dot{q}_i = {}^{C_i}({}^{B}\mathrm{V}_{\dot{\alpha}_i}) + {}^{C_i}({}^{B}\mathrm{V}_{\dot{\beta}_i}) \qquad (8)$$

${}^{B}\mathrm{V}_{\dot{\alpha}_i}$ is a component related with $\dot{\alpha}_i$ that is joint angular velocity of ${}^{A}V_{BORG}$. And ${}^{B}\mathrm{V}_{\dot{\beta}_i}$ is related with $\dot{\beta}_i$.

$${}^{C_i}({}^{B}\mathrm{V}_{\dot{\alpha}_i}) = {}^{C_i}_{B}\mathrm{R}\mathrm{J}_{\dot{\alpha}_i}(\dot{\alpha}_i) \qquad (9)$$

$${}^{C_i}({}^{B}\mathrm{V}_{\dot{\beta}_i}) = \dot{\beta}_i \begin{pmatrix} -r & 0 & 0 \end{pmatrix}^T \qquad (10)$$

$\mathrm{J}_{\dot{\alpha}_i}$ is a Jacobian matrix of ${}^{B}\mathrm{V}_{\dot{\alpha}_i}$, and r is a radius of sprocket.

Therefore, equation (8) can be change as

$$J_i^* \dot{q}_i = {}^{C_i}_{B}\mathrm{R}\mathrm{J}_{\dot{\alpha}_i}(\dot{\alpha}_i) + \dot{\beta}_i \begin{pmatrix} -r & 0 & 0 \end{pmatrix}^T \qquad (11)$$

Or

$$J_i^* \dot{q}_i = \begin{bmatrix} {}^{C_i}_{B}\mathrm{R} \begin{bmatrix} -l \sin \alpha_i \\ \\ -l \cos \alpha_i \end{bmatrix} & \begin{bmatrix} -r \\ \\ \\ \end{bmatrix} \end{bmatrix} \begin{bmatrix} \dot{\alpha}_i \\ \dot{\beta}_i \end{bmatrix} \qquad (12)$$

l is the link parameter between the joint and the crawler sprocket, and rotation matrix from $\{C_i\}$ to $\{B\}$ is as follows

$${}^{C_i}_{B}\mathrm{R} = \begin{bmatrix} x_B \bullet x_C & y_B \bullet x_C & z_B \bullet x_C \\ x_B \bullet y_C & y_B \bullet y_C & z_B \bullet y_C \\ x_B \bullet z_C & y_B \bullet z_C & z_B \bullet z_C \end{bmatrix} \qquad (13)$$

3 Verifying Simulation

In order to verify the proposed mathematical model, I simulated with DAFUL of "Virtual Motion" and MATLAB/Simulink, which can analyze multibody dynamics. The simulation conditions were as shown in Fig. 7, and the angular velocity of the leg connecting part and the crawler speed value of Fig. 10 were input to the multibody dynamics software and the proposed mathematical model as shown in Fig. 9. And outputs the state value of the system. The simulation was performed once for each of the pitch motion and the roll motion, and the results analyzed in the multi-body dynamics and the results in the proposed mathematical model.

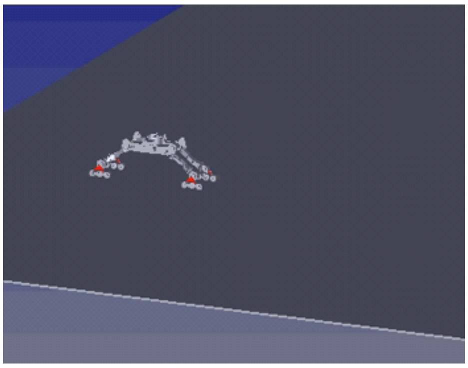

Fig. 7. Simulation Condition (Plat Road)

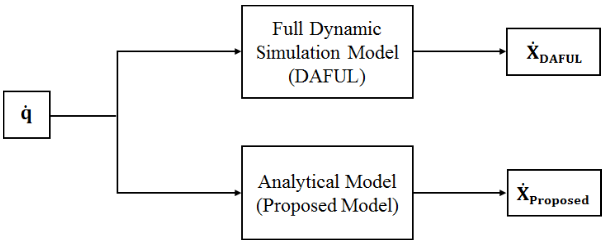

Fig. 8. Simulation Configuration

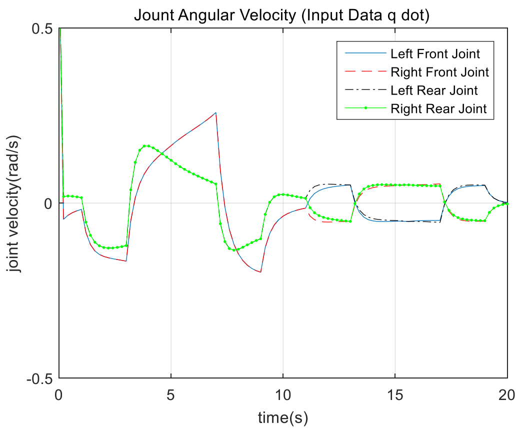

Fig. 9. Input Data Joint Angular velocity

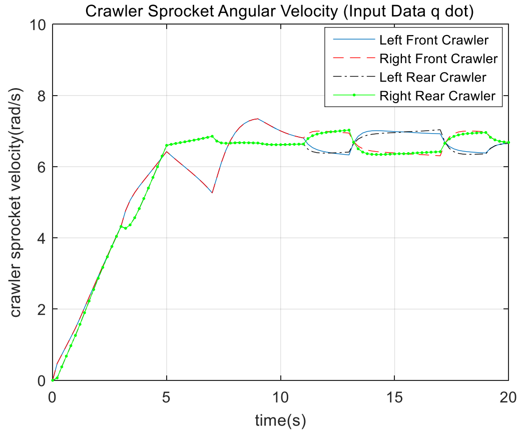

Fig. 10. Input Data Sprocket Angular velocity

Fig. 11 and Fig. 12, Fig. 13 denotes velocity values of the traveling system in the x direction, the y direction and the z direction, respectively. As shown in the graph, the velocity values in each direction analyzed from the proposed mathematical model can be confirmed to be similar to the simulation results from the multibody dynamics analysis.

Fig. 14 and Fig. 15, Fig. 16 denotes an angular velocity in the roll direction of the running system, an angular velocity in the pitch direction, and an angular velocity in the yaw direction. The roll, pitch, and yaw rate values interpreted from the proposed mathematical model are consistent with the simulation results from multibody dynamics analysis, confirming the usefulness of the proposed mathematical model.

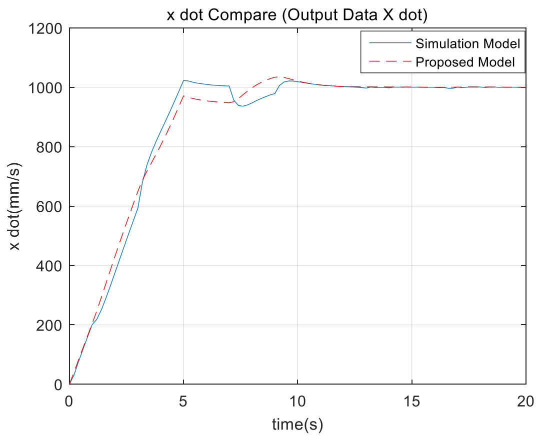

Fig. 11. Result of *x* dot state

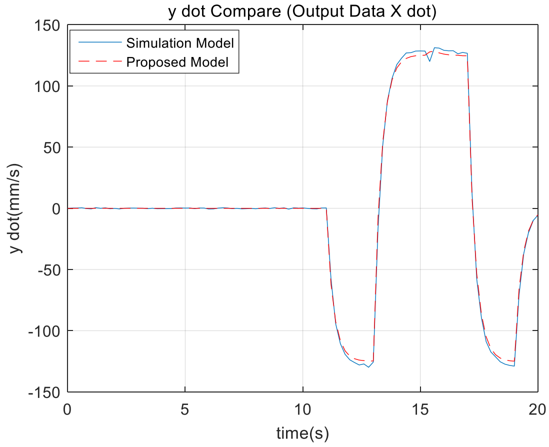

Fig. 12. Result of y dot

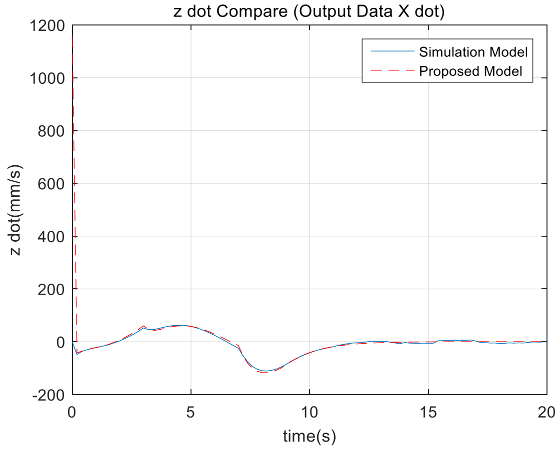

Fig. 13. Result of z dot

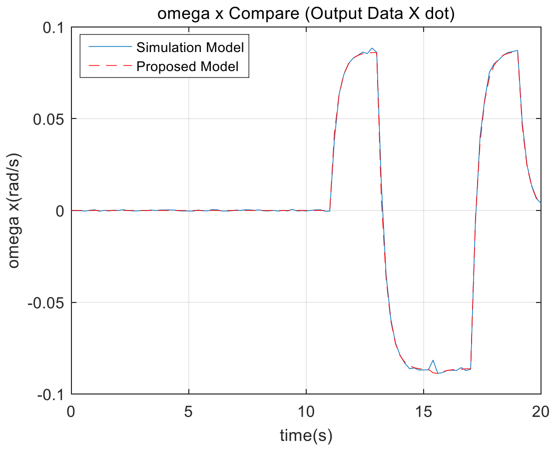

Fig. 14. Result of Ω_x

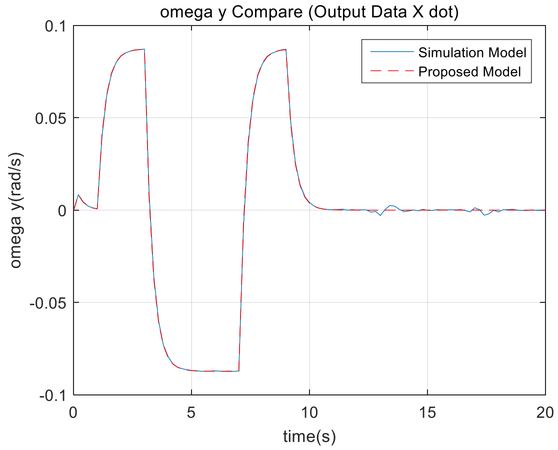

Fig. 15. Result of Ω_y

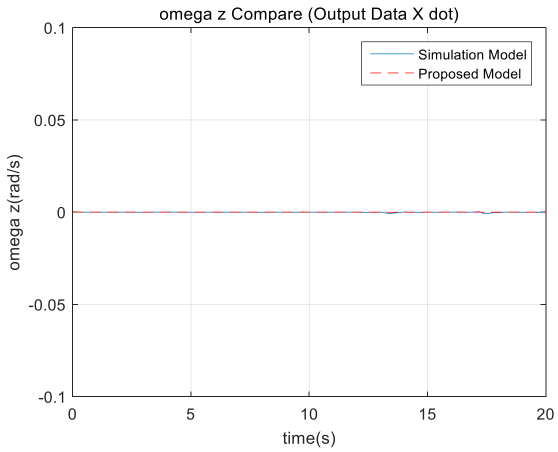

Fig. 16. Result of Ω_z

5 Conclusion

We have developed a mathematical model of a single Crawler-Leg system using a differential kinematic method and proposed a mathematical model for an entire system from a mathematical model for a single system. By comparing the proposed mathematical model with the results of the multibody dynamics simulation model, it is confirmed that the proposed model is useful.

However, it has limitations because it is a simulation that does not consider the realistic part such as characteristics of the hydraulic system etc. After this conference, we plan to apply algorithms to the real machine by complementing these defects.

Acknowledgment

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