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A Research on Designing, Manufacturing and Controlling of a Ship Motion Simulation System

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Abstract: Maritime transport is a popular way of transport in our country, but the risk that the cargoes may get damaged due to collisions and crashes inside the container is an unsolved problem. For that reason, the paper decided to research and design a system that can simulate the movement of a cargo ship as a premise for test the safety of the cargo securing process. This paper will propose the new design "Inverse delta structure", kinematics analysis, simulation and testing operation of the experimental model. The obtained results will be the basis for future experiments about durability and safety testing of secured cargoes on a ship.

Keywords: *Delta robot, Motion Simulation System.*

Introduction:

Maritime transport is one of the oldest methods of transportation in the world. Beside the advantages of large cargo quantity, short shipping time and reasonable cost, risks still exist that can lead to losses in cargo's quality and quantity. Among such risks, the collisions and the impact force during shipping process is one of the main causes. Realizing the necessary of the safety inspection of cargoes, a motion simulation system is researched and designed in this paper with the purpose to simulate the actual behavior of the ship at the sea.

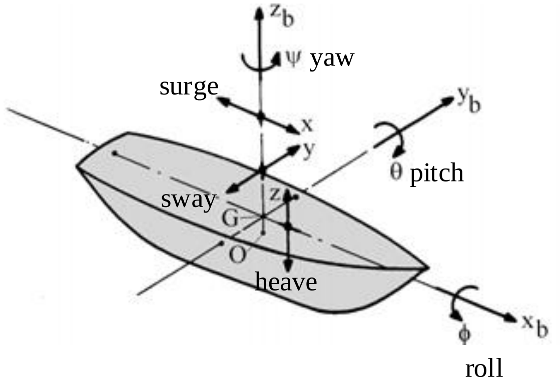


Figure 1: Definition of ship motion in 6-DOF

All kinds of ship movement can be divided into three types of linear motion: surge, sway, heave and three types of rotational motion: roll, pitch, yaw. (Figure 1) The most popular motion of the ship is wave moving which is the combination of surging and pitching motion. Thus, the trajectory of a point on the ship can be seen as a conic which will be considered as a circular in a ideal case (Figure 2). With Inverse Delta Robot structure, the system can create motion in three axes xyz. Therefore, other support components need to be supplemented to archived that circular trajectory.

In this paper, a system was designed and controlled for creating oscillating circular orbit with a specified frequency.

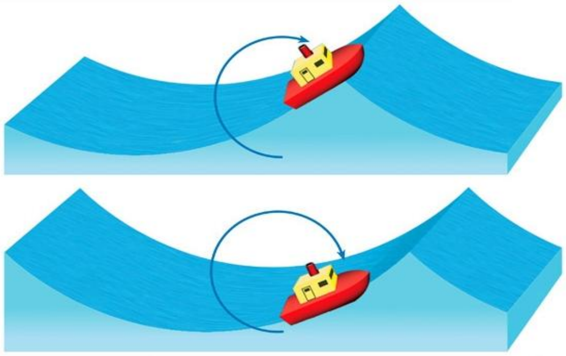


Figure 2: Circular trajectory of the ship

Mechanical Design:

The model was designed based on the requirements that can fluctuate in three xyz axes and carry 20 kg of cargoes without displacement. Since the weight of the cargoes is relatively large, the structures design must ensure that the system is stable when it oscillates with different frequencies. The model includes the following main components:

- I – Base component.
- II – Delta transmission component.
- III – Rotating support component.
- IV – Sliding & Rotating support component.
- V – Platform component.

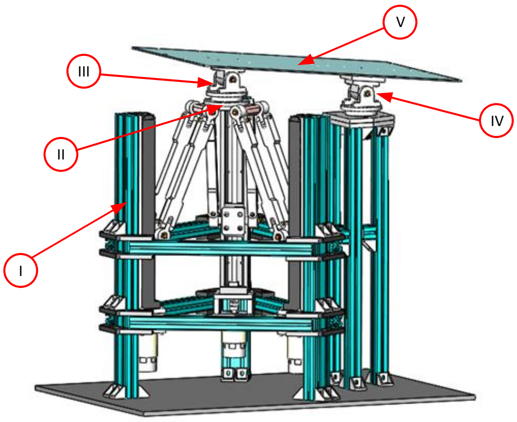


Figure 3: 3D model of the system

Model design analysis:

Base component (I) is designed based on shaped aluminum, which has many advantages: easy installation and replacement, good stiffness,…

Delta transmission component (II) in Figure 4 includes DC Servo Motors (1), linear actuators (2), links (3) and the Delta moving platform (4). This structure ensures that inverse delta workspace can reach 200 mm in each direction of x, y, z with the load capacity of 20 kg and operate flexibly at frequency $\frac{\pi}{15}$ rad/s.

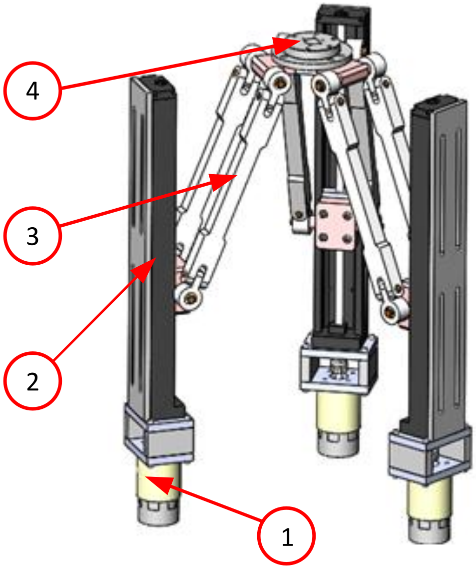


Figure 4: Delta transmission component

In addition, “Rotating support components (III)” and “Sliding and Rotating support components (IV)” were designed to link and transmit motion of the Delta moving platform (4) to the Platform component (V).

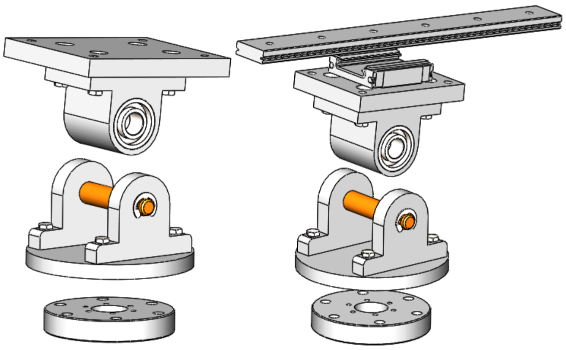


Figure 5: Support component (III) and (IV)

Kinematic analysis:

Overview of Delta Structure

Delta robot is a parallel robot with 3 DOF comprising a fixed base platform and a payload platform linked together by three independent, identical, and open kinematic chains which are driven by three linear actuators. The platform is connected with each drive by two links forming a parallelogram, allowing only translational movements of the platform and keeping the platform parallel to the base plane. This configuration features high stiffness in the vertical axis due to the symmetric design of 3 linear actuators.

Kinematic analysis

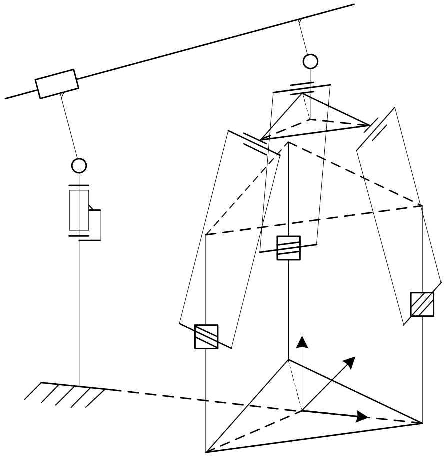


Figure 6: Mechanism diagram of the system

To build the inverse kinematic of the system, it’s necessary to divide the problem into two smaller inverses. In the first one, the position of the Platform C versus the position of the Delta motion platform B will be considered.

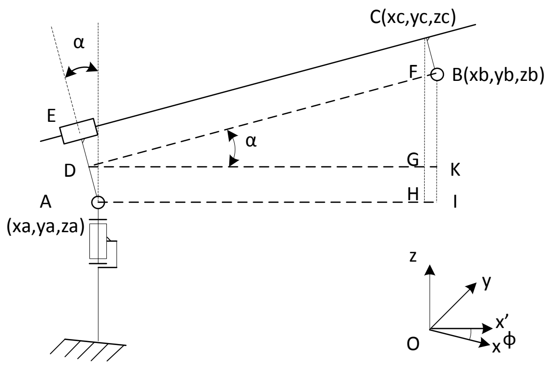


Figure 7: Mechanism diagram of the Platform

Known parameters:

AE; BC; A (x_a, y_a, z_a) ; C (x_c, y_c, z_c) .

So:

$$\begin{cases} x_b = x_a + \left(\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2} + BC.\sin\alpha\right)\cos\phi \\ y_b = y_a + \left(\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2} + BC.\sin\alpha\right)\sin\phi; \\ z_b = z_c - BC.\cos\alpha \end{cases} \tag{3.1}$$

Where:

$$\alpha = \left(\begin{array}{l} \arcsin\dfrac{z_c - z_a}{\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2 + (z_c - z_a)^2}} \\ -\arcsin\dfrac{AE}{\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2 + (z_c - z_a)^2}} \end{array} \right)$$

$$\phi = \arctan\left(\frac{y_c - y_a}{x_c - x_a}\right)$$

The second problem is the kinematic analysis of Vertical Delta structure (Figure 8):

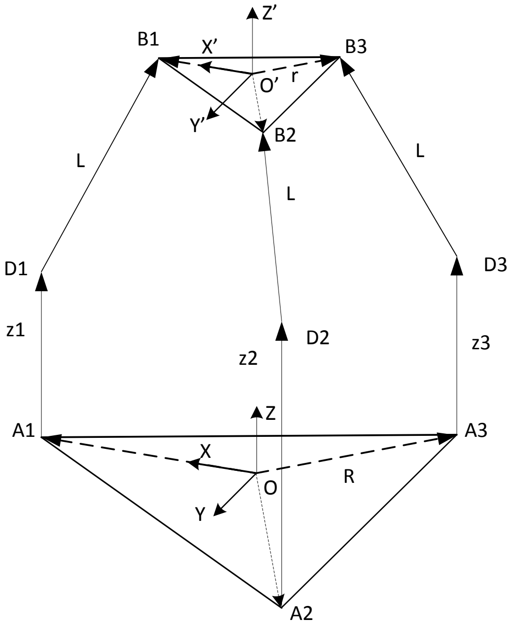


Figure 8: Delta structure in coordinate system

Set the absolute coordinate system {R}: Oxyz is located in the center of the triangle $A_1A_2A_3$, x - direction coincides with $\overrightarrow{OA_1}$ and z–direction is perpendicular to the plane $(A_1A_2A_3)$

Set the relative coordinate system {R'}: O'x'y'z' is located in the center of the triangle $B_1B_2B_3$, x' - direction coincides with $\overrightarrow{O'B_1}$ and z'–direction is perpendicular to the plane $(B_1B_2B_3)$

Based on the properties of equilateral triangles, then:

$$OA_i = R;\ O'B_i = r;\ D_iB_i = L;\ A_iD_i = z_i;\ i = 1,2,3$$

O' position in the absolute coordinate system {R}:

$$[O']_R = (x, y, z)^T \tag{3.2}$$

D_i position in the absolute coordinate system {R} (Figure 9):

$$[D_i]_R = (R.\cos\alpha_i,\ R.\sin\alpha_i,\ z_i)^T\ ;\ i = 1,2,3 \tag{3.3}$$

Where $\alpha_1 = 0; \alpha_2 = \frac{2}{3}\pi; \alpha_3 = -\frac{2}{3}\pi$;

Due to the characteristics of the parallelogram structure, the plane $(B_1B_2B_3)$ is always parallel to the plane $(A_1A_2A_3)$. Hence, B_i position can be determined by the following equations:

B_i position in O'x'y'z' coordinate (Figure 10)

$$[B_i]_{R'} = (r.\cos\alpha_i\ ,\ r.\sin\alpha_i,\ 0)^T,\ i = 1,2,3 \tag{3.4}$$

B_i position in Oxyz coordinate

$$\begin{aligned} [B_i]_R &= \overrightarrow{OO'} + \overrightarrow{O'B_1} \\ &= (r.\cos\alpha_i + x, r.\sin\alpha_i + y, z)^T; i = 1,2,3 \end{aligned} \tag{3.5}$$

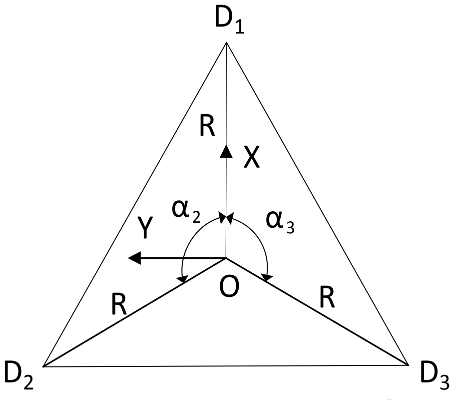


Figure 9: D_i position in Oxyz coordinate

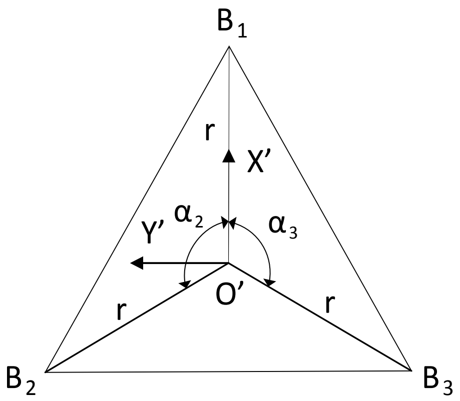


Figure 10: B_i position in O'x'y'z' coordinate

And

$$\left|\overline{D_iB_i}\right| = L, \quad i=1,2,3 \tag{3.6}$$

Combine (3.6) and (3.7)

$$(x-x_i)^2+(x-x_i)^2+(x-x_i)^2 = L^2; \; i=1,2,3 \tag{3.7}$$

So:

$$z_i = z - \sqrt{L^2-(x-x_i)^2-(y-y_i)^2}, \quad i=1,2,3 \tag{3.8}$$

Where $\begin{cases} x_i=(R-r).cos\alpha_i \\ y_i=(R-r).sin\alpha_i \end{cases}$

Combine (3.1) and (3.8), the inverse kinematic of the system will be established.

Simulation:

Simulation in Simulink Environment

This section will perform the simulation model operating under a circular trajectory. The simulation will check validity of the robot kinematic calculations in previous section which provides an intuitive view of the oscillation of the motion platform in the real. Simulink function was used to import the model to the Simulink environment.

After putting the system in the simulation environment, linear control blocks and central control blocks were built and applied kinematic equations to simulate in order to reduce errors in the actual control of the system.

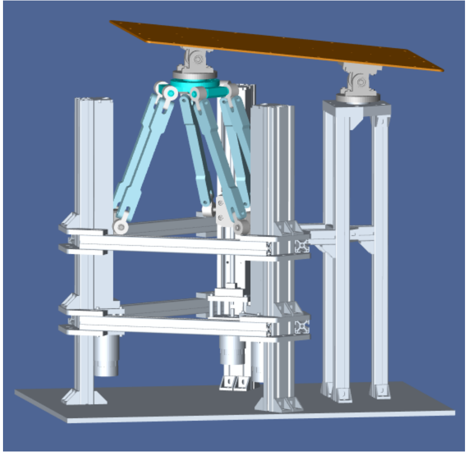


Figure 11: Delta motion platform in Simulink environment

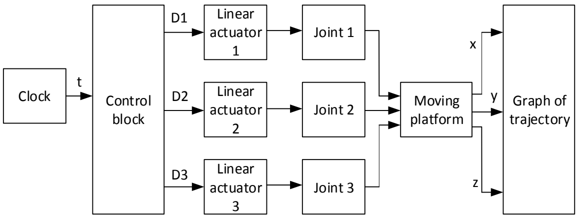


Figure 12: Flowchart of control system in Simulink environment

Control algorithms

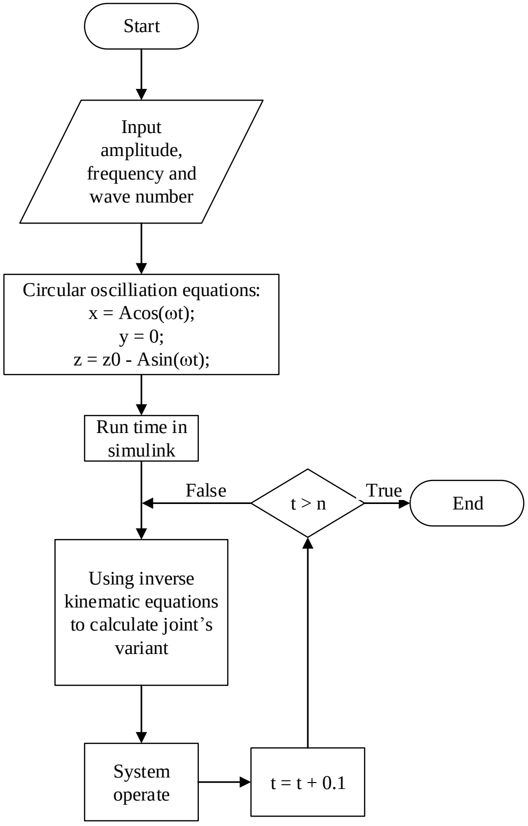


Figure 13: Flow chart simulation of the system

Simulation results:

With the input parameter of the oscillation: 100 mm of amplitude, π /15 rad/s of frequency and 5 oscillation periods, the results are shown in Figure 14, Figure 15, Figure 16.

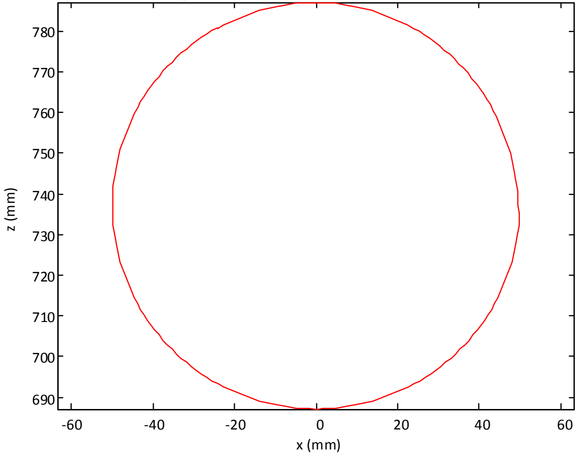


Figure 14: Simulation trajectory of motion platform

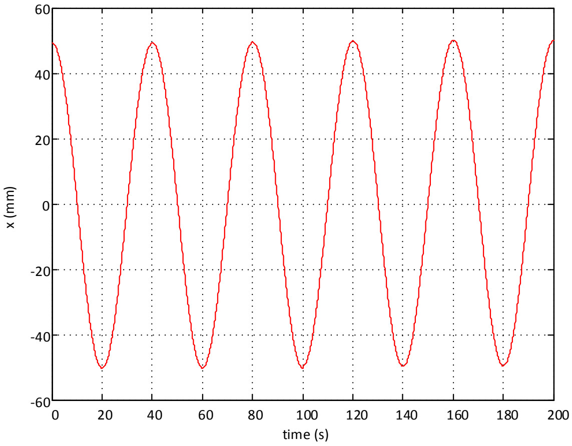


Figure 15: x position versus time

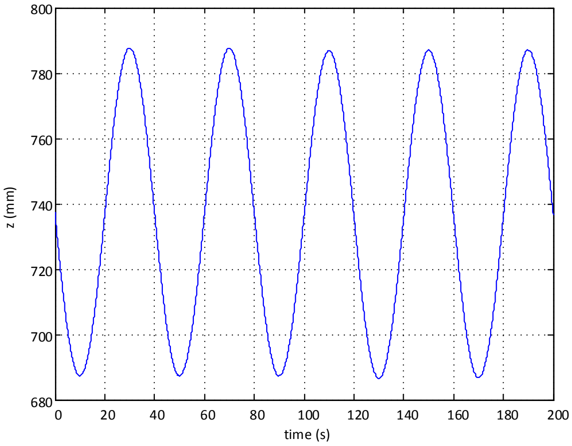


Figure 16: z position versus time

Experimental model:

Control system

The control system in Figure 17 was designed to control three linear motors. This research built a communication program in the computer via Matlab. The amplitude and frequency of desired trajectory are inputted to the program. Then, the program will calculate kinematic equations to get the output parameters Δd_i, encode them into a frame and transfer them to the microcontroller via the RS 232 standard.

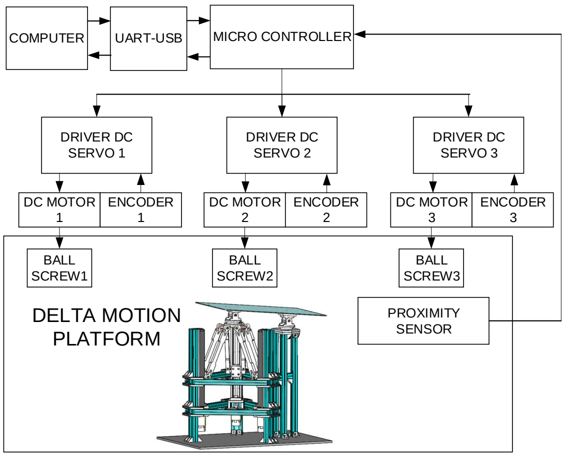


Figure 17: Control system diagram

When these analyzed signals were received from the computer, the microcontroller will generate control pulse based on the synchronization algorithm (Figure 18) to control three motors for completing these calculated distance Δd_i in the sampling time.

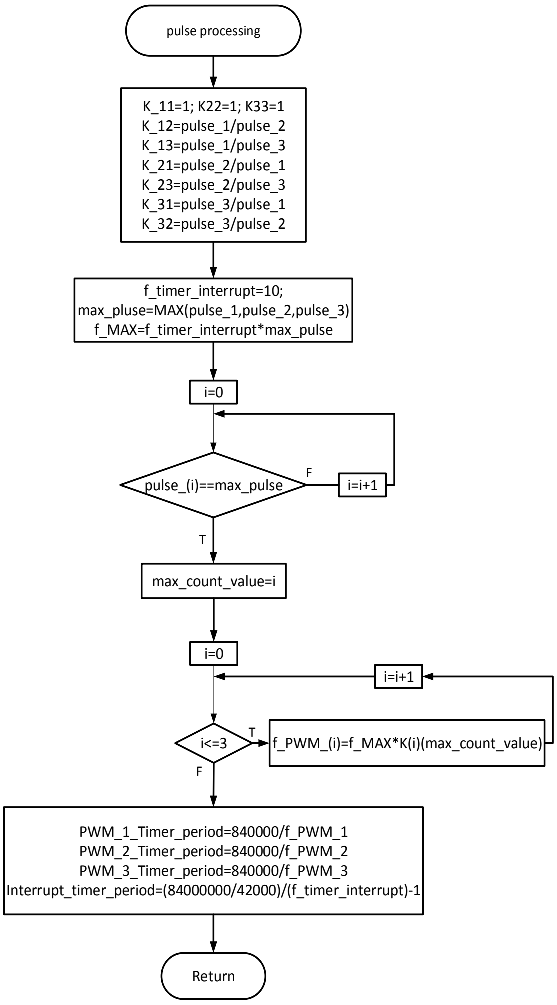


Figure 18: The synchronization algorithm

Manufacturing and experimental model

After designing and simulating, the experimental model in Figure 18 was built and installed with the control system.

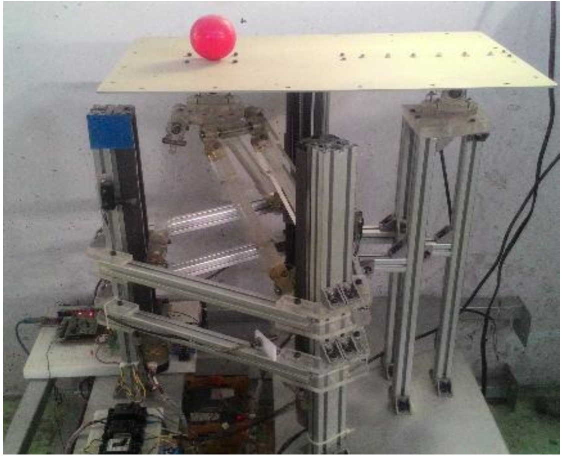
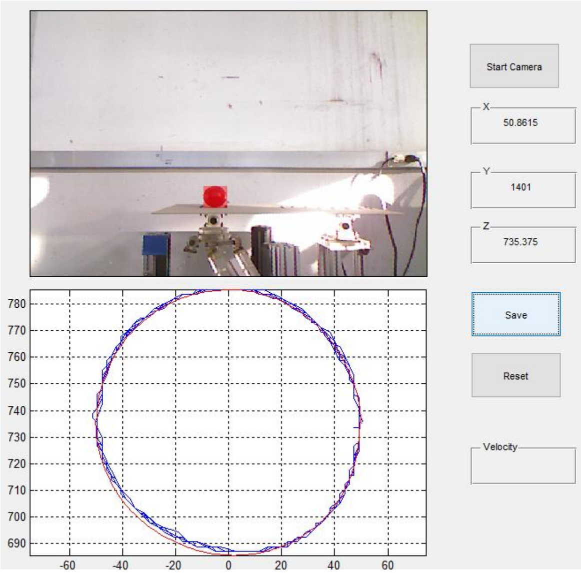


Figure 19: Experimental model

In addition, a red ball is attached to the platform to verify the actual operation trajectory. Camera is used to track this ball's position and a graphical user interface is built for an intuitive view of the operation trajectory in Figure 19.



X: 50.8615
Y: 1401
Z: 735.375

Figure 20: Trajectory of platform using camera

As can be seen from the results of x, z position versus time (Figure 21 and Figure 22), they have a start-time and end-time period. Hence, the full time working is determined by the difference between end-time and start-time (Figure 23). The actual working time is recorded as 152.56 s for 5 cycles. Therefore, the actual frequency is 0.2059 rad/s, deviation of 1.7% compared to the desired frequency.

In the trajectory error graph (Figure 24), the average error is about 1 mm and the peak is about 3.7 mm. The amplitude error is in the range of 4%, so the results of control process are quite accurate.

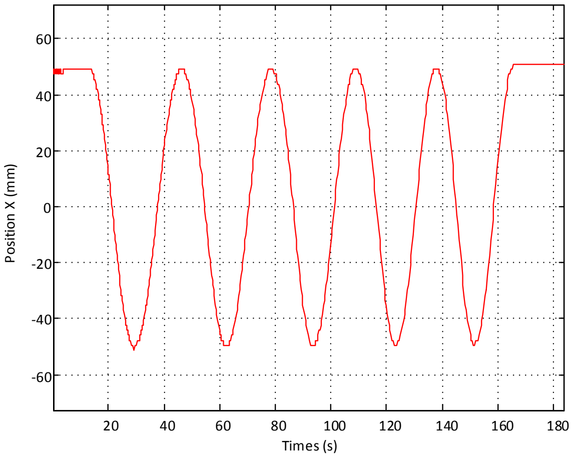


Figure 21: x position using camera

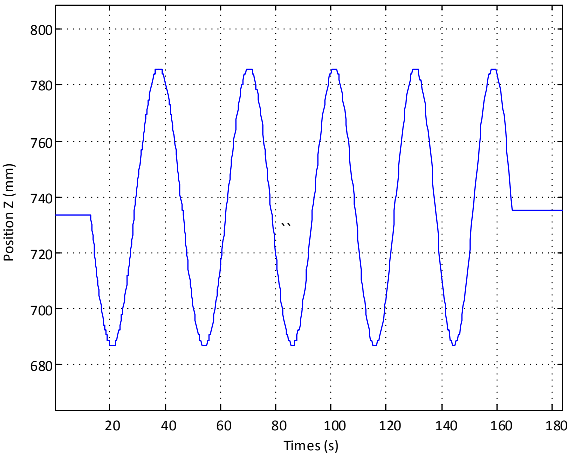


Figure 22: z position using camera

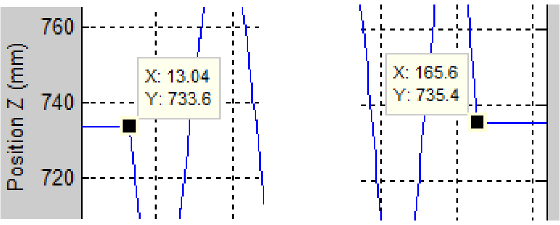


Figure 23: Start-time and end-time period of z

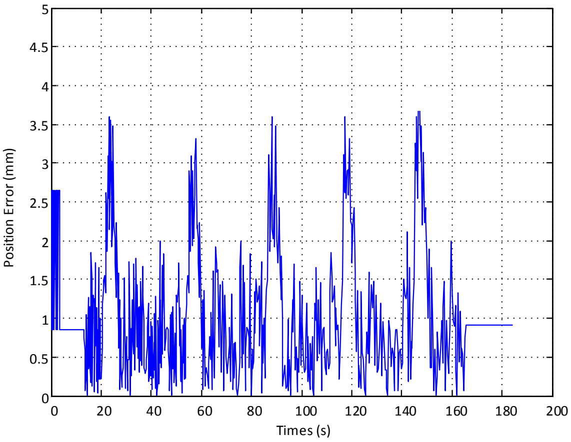


Figure 24: Trajectory error versus time

Conclusion:

A ship motion simulation system based on Delta structure was successfully studied in this research. The execution process not only provides a design analysis and a simulated operation but also manufactures and controls an experimental model to verify the control algorithm.

The obtained results of this paper are summarized as follows:

(i) A new motion simulation system has been proposed and completed.
(ii) Model analysis of system guarantees the design requirements.
(iii) Inverse Delta kinematics was analyzed and solved.
(iv) Experimental results have given a good response of frequency and amplitude with an acceptable error range.

Finally, this system is a premise research for cargoes safety, contributes to the increase in productivity and quality in cargo transportation.

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