Simulation and Experiment Study of a Turbine Access System with Six-Axial Active Motion Compensation

液壓六軸主動補償式離岸風機登塔系統之研究

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Outline

- Research Background
- System Structure
- Ship Motion Modeling
- Kinematics Analysis
- Dynamics Analysis
- Results
- Conclusion

Research Background

- Taiwan government have large development plan for offshore wind power.
- For wind turbine construction and maintenance, stuffs and equipment entering and leaving offshore wind turbines are important issues.
- **Turbine Access System (TAS)** aims to enhance the safety of the operator in offshore construction.

Fig. 2

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Research Background

The TAS of Houlder

Source: Web side of Compnyh Houlder

The TAS of Ampelmann

Source: Web side of Ampelmann

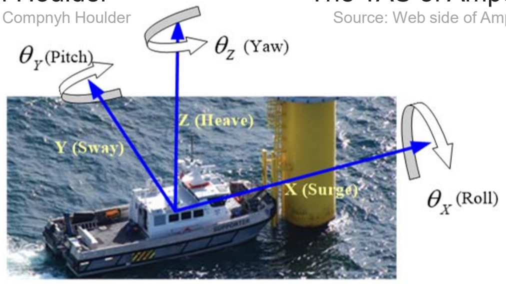

Fig. 3

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台電一期離岸風場實際應用

Fig. 4

Outline

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Fig. 5

Structure of TAS with 6-DOF compensation

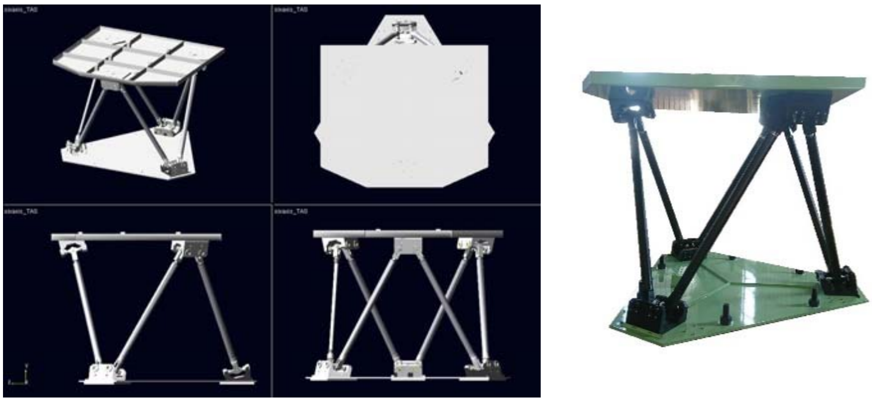

Fig. 6

Structure of TAS with 6-DOF compensation

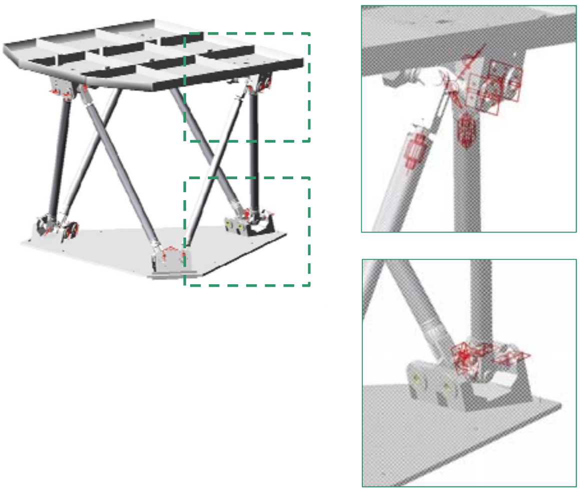

Fig. 7

Block diagram of TAS with 6-DOF compensation

Simulation

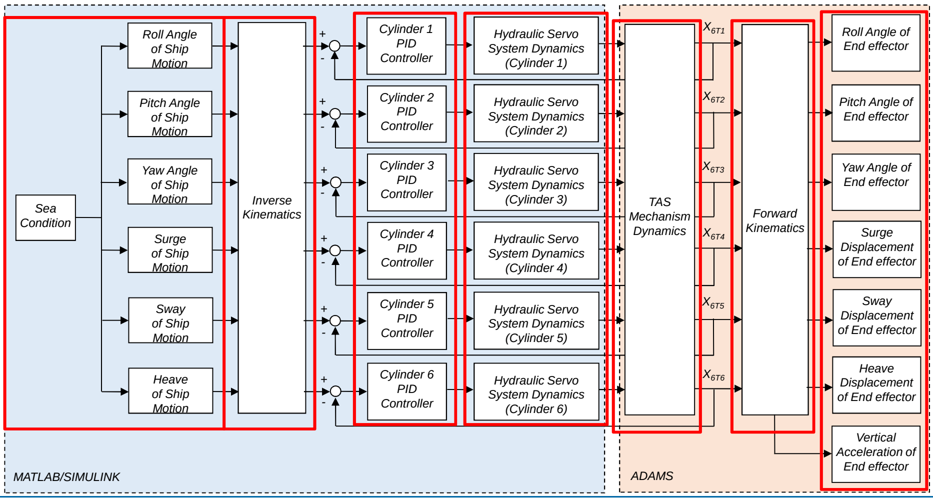

Fig. 8

Block diagram of TAS with 6-DOF compensation

Experiment

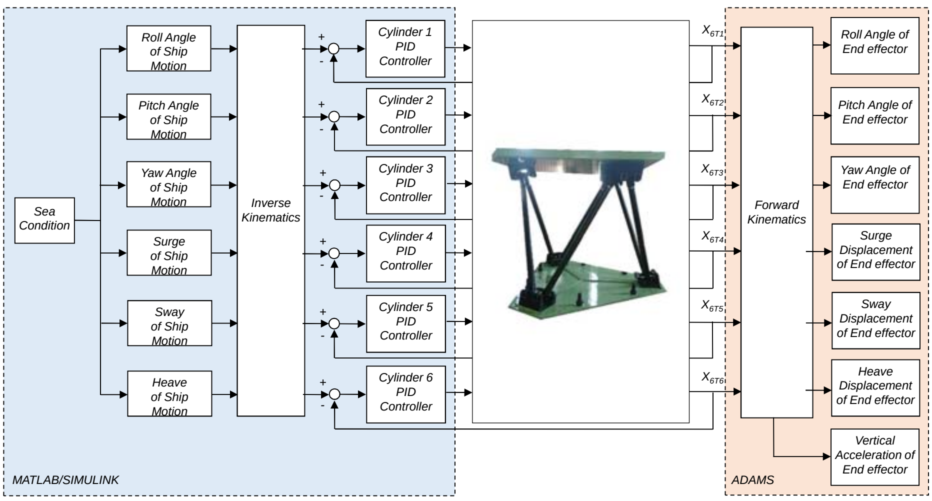

Fig. 9

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Fig. 10

Ship Modeling

Main parameters:

1. Wave height
2. Wave length
3. Wave period
4. Wave direction

Parameters sourced from: SOIC
Ship and Ocean Industries R&D Center

Method of Ship Motion:
Pinkster, J.M.J. Journée and Jakob., Introduction in Ship Hydromechanics. s.l. : Delft University of Technology, 2002.

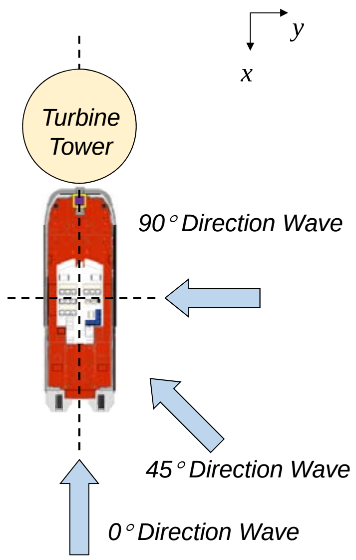

Fig. 11

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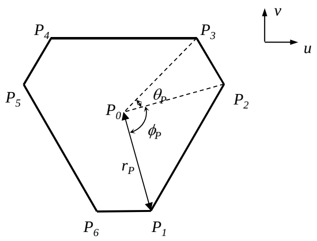
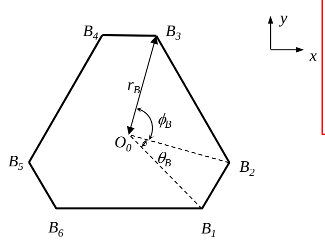
Fig. 12

Inverse Kinematics (TAS with 6-DOF compensation)



$$\mathbf{P}_i = \begin{bmatrix} r_P \sin(\lambda_{Pi}) \\ -r_P \cos(\lambda_{Pi}) \\ 0 \end{bmatrix} \equiv \begin{bmatrix} P_{ix} \\ P_{iy} \\ P_{iz} \end{bmatrix}, \quad \lambda_{Pi} = \frac{i\pi}{3} - \frac{\phi_P}{2} \quad i = 1,3,5; \quad \lambda_{Pi} = \lambda_{P(i-1)} + \phi_P \quad i = 2,4,6$$

$$\mathbf{B}_i = \begin{bmatrix} r_B \sin(\lambda_{Bi}) \\ -r_B \cos(\lambda_{Bi}) \\ 0 \end{bmatrix} \equiv \begin{bmatrix} B_{ix} \\ B_{iy} \\ B_{iz} \end{bmatrix}, \quad \lambda_{Bi} = \frac{i\pi}{3} - \frac{\theta_B}{2} \quad i = 1,3,5; \quad \lambda_{Bi} = \lambda_{B(i-1)} + \theta_B \quad i = 2,4,6$$



$$\mathbf{l}_i = \mathbf{R}_{\alpha\beta\gamma}\mathbf{P}_i^{\,P} + \mathbf{D} - \mathbf{B}_i \qquad (i = 1,2,...,5,6)$$

$$\|\mathbf{l}_i\| = p_x^{\,2} + p_y^{\,2} + p_z^{\,2} + r_P^{\,2} + r_B^{\,2} + 2(r_{11}P_{ix}^{\,P} + r_{12}P_{iy}^{\,P})(P_x - B_{ix})$$
$$+2(r_{21}P_{ix}^{\,P} + r_{22}P_{iy}^{\,P})(P_y - B_{iy}) + 2(r_{31}P_{ix}^{\,P} + r_{32}P_{iy}^{\,P})P_z - 2(P_xB_{ix} + P_yB_{iy})$$
$$\text{for } i = 1,2,...,5,6$$

Fig. 13

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Fig. 14

Mathematical model of hydraulic servo system

- **Dynamic model of the spool**
- **Orifice equation of the hydraulic servo system**
- **Continuity equation of the hydraulic cylinder**

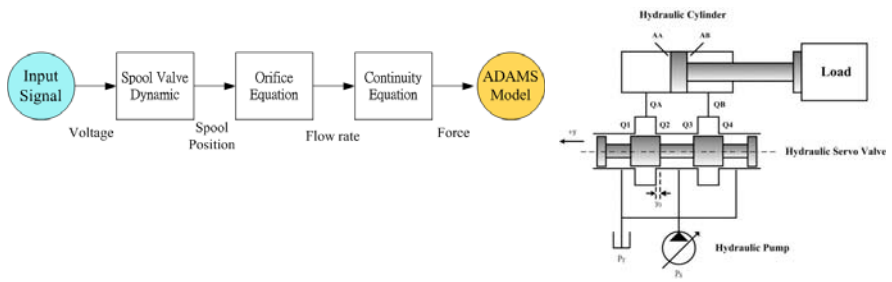

Fig. 15

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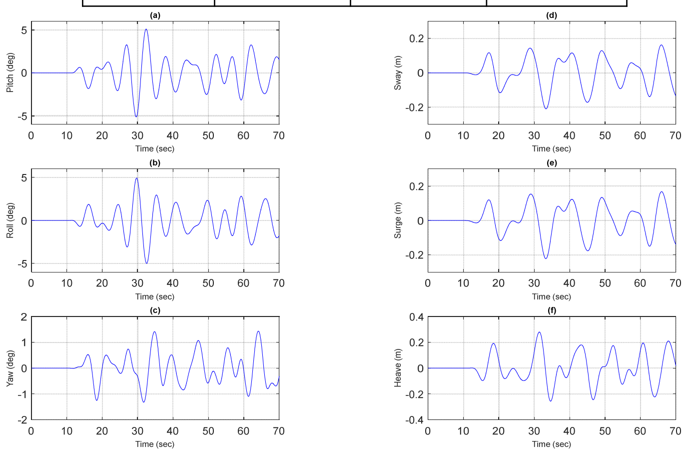
Fig. 16

Data of the wave (TAS with 6-DOF compensation)

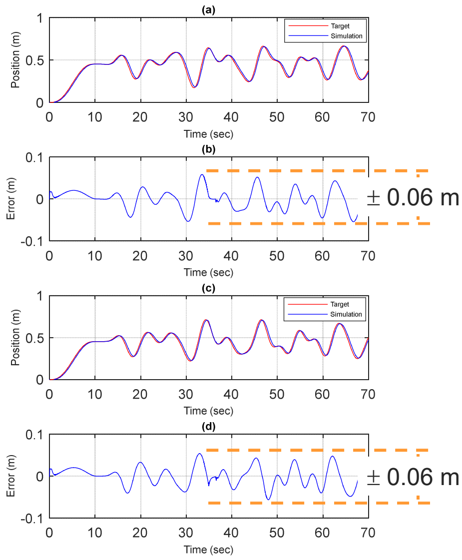
Wave Direction	Simulation time	Significant wave height	Wave Period
45°	70 sec	0.5 m	7.5 sec



(a)Pitch、(b)Roll、(c)Yaw (d)Sway、(e)Surge、(f)Heave

Fig. 17

Results



(a) 1st Hydraulic cylinder position control response

(b) Control error of 1st hydraulic cylinder position control response

(c) 2nd Hydraulic cylinder position control response

(d) Control error of 2nd hydraulic cylinder position control response

Fig. 18

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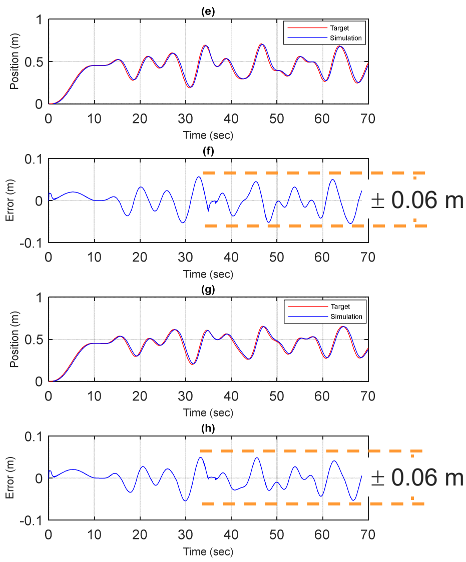
Results



(e) 3rd Hydraulic cylinder position control response

(f) Control error of 3rd hydraulic cylinder position control response

(g) 4th Hydraulic cylinder position control response

(h) Control error of 4th hydraulic cylinder position control response

Fig. 19

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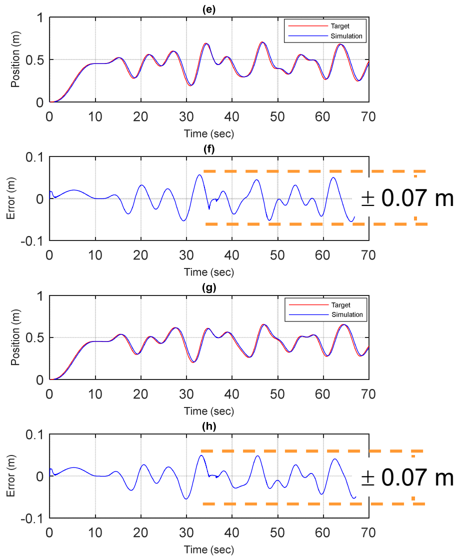
Results



(i) 5th Hydraulic cylinder position control response

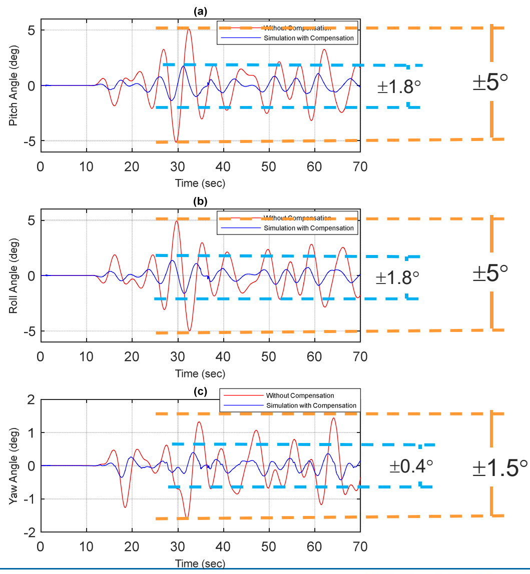
(j) Control error of 5th hydraulic cylinder position control response

(k) 6th Hydraulic cylinder position control response

(l) Control error of 6th hydraulic cylinder position control response

Fig. 20

Comparison of with and without compensation



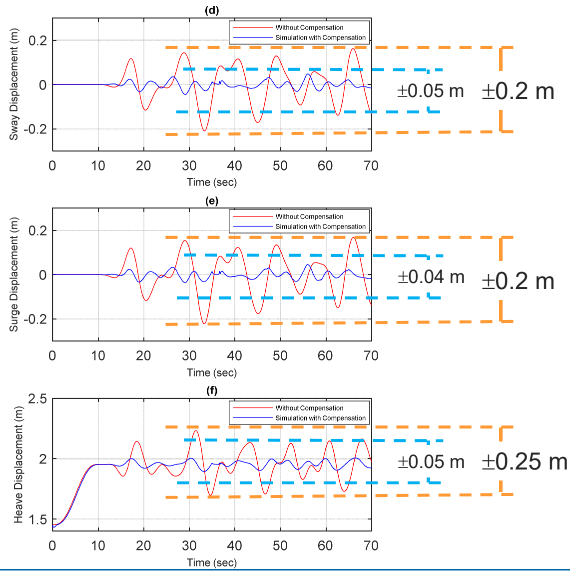
(a) Pitch angle response of end effector

(b) Roll angle response of end effector

(c) Yaw angle response of end effector

Fig. 21

Comparison of before and after compensation



(d) Sway displacement response of end effector

(e) Surge displacement response of end effector

(f) Heave displacement response of end effector

Fig. 22

Experiment Results

Fig. 23

Simulation Results

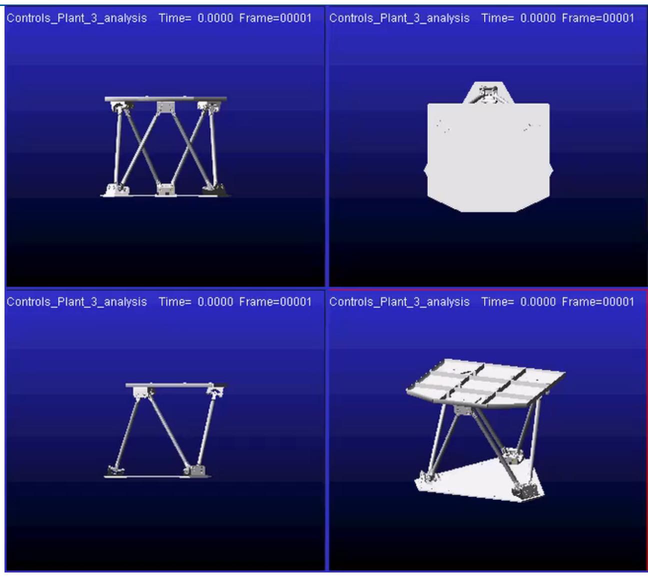


Fig. 24

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Fig. 25

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Conclusion

- This study developed a TAS with a 6-DOF active motion compensation system for offshore wind farms in the Taiwan Strait, under sea conditions with a wave period of 7.5 sec and significant wave height of 0.5m. The system is driven by active motion compensation control systems using PID.
- The dynamic co-simulation of TAS via ADAMS and MATLAB/SIMULINK were achieved to confirm the system design and parameters.
- The TAS proposed in this study has been verified in both simulation and experiment with satisfactory active motion compensation performance.

Fig. 26

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Fig. 27

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