X-stern 배열을 가진 대형급 무인잠수정의 경로점 추적

Waypoint Tracking of Large Diameter Unmanned Underwater Vehicles with X-stern Configuration

Do Wan Kim · Moon Hwan Kim · Ho-Gyu Park · Tae-Yeong Kim

Abstract - This paper focuses on a horizontal waypoint tracking and a speed control of large diameter unmanned underwater vehicles (LDUUVs) with X-stern configuration plane. The concerned design problem is converted into an asymptotic stabilization of the error dynamics with respect to the desired yaw angle and surge speed. It is proved that the error dynamics under the proposed control scheme based on the linear control and the feedback linearization can be considered as a cascade system: the cascade system is asymptotically stable if its nominal systems are so. This stability connection enables to separately deal with the waypoint tracking problem and the speed control one. By using the sector nonlinearity, the theoretical claims.

Keywords: Unmanned Underwater Vehicles (UUV), X-stern, Lyapunov, Linear Matrix Inequality (LMI), Waypoint, Asymptotic stability
velocities, respectively, and \( r \) is the angular velocity in yaw (see [9-11] for more details).

**Assumption 1 ([9-11]):** Assume that

i. the vehicle is the top-bottom (zy-plane) and port-starboard (xz-plane) symmetry;

ii. the vehicle is equipped with the X-stern and a propeller to provide the forward thrust;

iii. the origin of the body-fixed frame is same to the center of gravity of the vehicle;

iv. the center of gravity coincides with the center of buoyancy;

v. any damping terms greater than second-order are negligible;

vi. the heave, pitch, and roll motions can be neglected;

vii. the \( y \)-position of the center of gravity is negligible.

Under Assumption 1 and the definitions \( \eta := [x\ y\ y]^T \in \mathbb{R}^3 \) and \( \phi := [u\ v\ r]^T \in \mathbb{R}^3 \), the kinematics and dynamics of UUV are represented by

\[
\dot{\eta} = J\eta \phi \\
M\dot{\phi} + f(\phi) = \tau
\]

where \( J \in \mathbb{R}^{3\times3} \) is a frame transformation, \( M \in \mathbb{R}^{3\times3} \) includes mass and hydrodynamic added mass terms and \( f(\phi) \phi \in \mathbb{R}^3 \) captures Coriolis-centripetal matrices including the added mass and a damping matrix, \( \tau \) is the control actuator forces with the propeller thrust \( \xi \), and \( \delta_i \), \( i \in I_k \) is the rudder angles defined as

\[
\tau = \left[ \begin{array}{c}
\xi + X_{\text{add}}u \sum_{i=1}^{N} \delta_i \\
u \sum_{i=1}^{N} Y_{\delta_i} \\
u \sum_{i=1}^{N} N_{\delta_i}
\end{array} \right] \in \mathbb{R}^3.
\]

The matrices \( J, M, \text{ and } f \) are given by

\[
J = \begin{bmatrix}
\cos(\phi) & -\sin(\phi) & 0 \\
\sin(\phi) & \cos(\phi) & 0 \\
0 & 0 & 1
\end{bmatrix},
M = \begin{bmatrix}
m_1 & 0 & 0 \\
0 & m_2 & m_3 \\
0 & m_3 & m_2
\end{bmatrix},
f = \begin{bmatrix}
-X_{u}u - X_{\delta_i}v - mw - mx\delta_i - X_{r}r \\
0 - Y_{u}u - Y_{\delta_i}v - \mu - Y_{r}r - Y_{\delta_i}\left| r \right| \\
0 - N_{u}u - N_{\delta_i}v - mxu - N_{r}r - N_{\delta_i}\left| r \right|
\end{bmatrix},
\]

in which \( m_1 = -X_{u}, \ m_2 = m - Y_{r}, \ m_3 = mx_\delta, \ m_4 = I_{\delta}, \ \text{and } m \) is the vehicle mass, \( x_\delta \) is the \( x \)-position of the center of gravity, \( I_{\delta} \) is the mass moment of inertia term. The related coefficients are listed in Appendix 1, which are obtained by computational fluid dynamics (CFD) and empirical formulations based on hull geometry for LIG Nex1 LDUUV.

**Problem 1:** Consider UUV described by (1) and (2), its desired constant forward speed \( u_{d} \in R_{u_d} \) and its desired line of sight to be the horizontal plane angle defined as

\[
\psi_d = \tan^{-1}\frac{e_y}{e_x}
\]

where \( e_x = x - x_{d}, \ e_y = y - y_{d}, \ \text{and } (x_{d},y_{d},k \in I_{u_d} \text{ is the } k \text{th given waypoint, Design } \xi \text{ and } \delta, \ i \in I_k \text{ such that both } [e_x, e_y, r] \text{ asymptotically converge to zero, where } e_x = u - u_d \text{ and } e_y = \psi - \psi_d.\n
**Remark 1:** From the UUV with the X-stern (1) and (2), setting \( X_{\text{add}} = 0, \ Y_{\text{add}} = Y_{\text{add}}, \ N_{\text{add}} = N_{\text{add}}, \text{ and } \delta = \delta \text{ for } i \in I_k \text{ all simplifies an UUV with cruciform stern.}\n
## 3. Main Results

Before proceeding to our main results, the following propositions and lemma will be needed throughout the proof:

**Proposition 1:** Consider (1) and (2). Define \( \chi := \text{col}[e_x, e_y, r] \in \mathbb{R}^3 \) and \( \xi := \text{col}[\delta_x, \delta_y, \delta_r] \in \mathbb{R}^3 \), an augmented error system is described by

\[
\begin{bmatrix}
\dot{\chi} \\
\dot{e}_u \\
\dot{F}_1\\
\dot{F}_2
\end{bmatrix} =
\begin{bmatrix}
F_1(e_x, e_y, e_r, r, \delta) \\
F_2(e_x, e_y, e_r, \delta) \\
F_3(e_u) \\
F_4(e_u)
\end{bmatrix}
\begin{bmatrix}
\chi \\
e_u \\
F_1(\delta) \\
F_2(\delta)
\end{bmatrix} +
\begin{bmatrix}
0 \\
G \\
0 \\
0
\end{bmatrix}
\begin{bmatrix}
\xi \\
\delta
\end{bmatrix}
\]

where

\[
F_1 = E^{-1} \begin{bmatrix} u_x \sin e_u & \cos e_u \\
\|e_u\| & \|e_u\| & 1 \\
0 & Y_u + Y_{\delta_i} |v| & -\mu + Y_r + Y_{\delta_i} |v| + N_r |v| + N_{\delta_i} |v| \\
0 & N_y + N_{\delta_i} |v| & -mxu + N_y + N_{\delta_i} |v| + N_r |v| + N_{\delta_i} |v|
\end{bmatrix}
\]

\[
F_2 = E^{-1} \begin{bmatrix}
\sin e_u \\
\|e_u\| & \|e_u\|
\end{bmatrix}
\begin{bmatrix}
-mx + (e_u + 2u_d) \sum_{i=1}^{N} Y_{\delta_i} \\
-mx_r + (e_u + 2u_d) \sum_{i=1}^{N} N_{\delta_i}
\end{bmatrix}
\]

\[
F_3 = \frac{1}{m_1} \begin{bmatrix}
X_{u}u - X_{\delta_i}v + mxu - X_{r}r \\
0
\end{bmatrix}
\]

\[
F_4 = \frac{1}{m_1} \begin{bmatrix}
X_{u}e_u + 2X_{u}u_d + X_{\delta_i}e_u + 2u_d \sum_{i=1}^{N} \delta_i
\end{bmatrix}
\]
Then the closed-loop system takes the following cascade arrangement:

\[
F = \frac{1}{m_1} \left( X_u u_d + X_{ud} \delta \sum_{i=1}^\infty \delta^i \right)
\]

\[
G = E^{-1} \begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & Y_{u_b} u_d & 0 \\
0 & Y_{u_a} \delta & 0 & 0 \\
Y_{u_b} \delta & 0 & 0 & 0
\end{bmatrix}, \quad E = \begin{bmatrix} 1 & 0 & 0 \\ 0 & m_2 & m_3 \\ 0 & m_4 & m_5 \end{bmatrix}.
\]

**Proof:** Differentiating (3), substituting (1) into it, and using (2) and (e) yield:

\[
\dot{e}_v = \frac{u_a \sin e_v}{\| \{e_x, e_y\} \|} + \cos e_v \dot{r} + \sin e_v \dot{\theta} - e_v
\]

(see [7] for more details). From (2) and (e), we see that

\[
\frac{\dot{e}_v}{e_v} = \left[ \begin{array}{c} m_1 m_2 \\ m_1 m_3 \\ m_1 m_4 \\ m_1 m_5 \end{array} \right]^{-1} \left[ \begin{array}{c} Y_x + Y_{r|v} |r| -m_e + u_d + Y_x + Y_{r|v} |r| \\ N_x + N_{r|v} |r| -m_x + u_d + N_x + N_{r|v} |r| \end{array} \right] + \left[ \begin{array}{c} e_v^2 + 2u_a e_v + u_d^2 \\ e_v^2 + 2u_a e_v + u_d^2 \end{array} \right] \sum_{i=1}^\infty \delta^i
\]

and

\[
\dot{e}_u = \frac{1}{m_1} \left( X_u e_v^2 + 2X_u e_v u_d + X_u u_d^2 + X_u + m_e r^2 + m_x r^2 \right)
\]

\[
+ X_u r^2 + \dot{\theta} + X_{ud} \delta \left( e_v^2 + 2u_a e_v + u_d^2 \right) \sum_{i=1}^\infty \delta^i
\]

Taking the change of variables, we have an augmented error system becomes (4).

**Proposition 2:** Consider (4). Let

\[
\delta = K \theta
\]

\[
\xi = -m_1 F_e(e_x, e_y, v, \phi, \psi) \chi - m_1 F_e(e_x, e_y, \delta, \delta, \delta) \delta e_u
\]

(5)

(6)

where \( K \) is the controller gain to be determined and \( \gamma \in R_{+} \). Then the closed-loop system takes the following cascade form:

\[
\Sigma_1: \dot{\chi} = (\chi + F_e) + F_e \dot{\chi}
\]

(7)

\[
\Sigma_2: \dot{e}_u = -\gamma e_u
\]

(8)

**Proof:** The proof directly follows from [Lemma 1, 7].

**Proposition 3:** It is true that

\[
F_e = \sum_{i=1}^\infty \sum_{j=1}^\infty \sum_{k=1}^\infty \sum_{l=1}^\infty \theta_i \theta_j \theta_k \theta_l A_{ijkl},
\]

on \( B_i \times B_j \), where \( \theta_i, \theta_j, \theta_k, \theta_l \) and \( A_{ijkl} \) are given in Appendix 2.

**Proof:** The proof directly follows from [Theorem 2, 7].

**Lemma 1:** There exists \( \zeta \in R_{+} \) such that

\[
|F_e| < \zeta
\]

on \( B \times B \times B \times B \times B \times B \).

**Proof:** It is not hard to see that choosing

\[
\zeta \geq |E|^{-1} \begin{bmatrix} \rho \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |Y_{ud} \delta| \\ m_x \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |N_{uv} \delta| \end{bmatrix}
\]

implies

\[
|F_e| \leq |E|^{-1} \begin{bmatrix} \rho \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |Y_{ud} \delta| \\ m_x \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |N_{uv} \delta| \end{bmatrix} \leq \zeta
\]

on \( B \).

The following Theorem gives an LMI formulation of the Problem 1:

**Theorem 1:** Consider (1) and (2) under (5) and (6) and Propositions 1 and 2. Let \( \Omega = \{ \{e_x, e_y\} \in R^4 : \chi^T P_k + a e_a^2 < 1 \} \). Suppose that i) \( \Omega \subset B \); ii) there exist \( \tilde{P} = \tilde{P}^T > 0 \) and \( \tilde{K} \) such that

\[
\text{Sym} \left[ A_{ijkl} P_k \tilde{G} \right] < 0
\]

(9)

\[
E_k P_k^T < \Delta_k^2
\]

(10)

\[
E_k^T P_k^T < \Delta_k^2
\]

(11)

\[
\left| \Delta_k^2 \right| \tilde{K} \leq 0
\]

(12)

for all \( \{i_1, i_2, i_3, i_4\} \in L \times L \times L \times L \). Then, for \( \{e_x, e_y\} \in \Omega \), the null space of (1) and (2) under (5) and (6) asymptotically converge to zero as \( t \to \infty \). In this feasible case, \( P = \tilde{P}^T \) and \( K = \tilde{K} P_k^T \).

**Proof:** Consider a Lyapunov function

\[
V(e_x, e_y) = \chi^T P_k + a e_a^2
\]

for \( a \in R_{+} \). Its derivative becomes

\[
V_{\phi}(e_x, e_y) \leq \chi^T P_k F_e + \chi^T P_k \tilde{G} \chi + 2 \chi^T P_k F_e e_v - 2 \chi^T P_k e_a^2
\]

(9)

(10)

(11)

(12)

\[
\sum_{i=1}^\infty \sum_{j=1}^\infty \sum_{k=1}^\infty \sum_{l=1}^\infty \theta_i \theta_j \theta_k \theta_l A_{ijkl},
\]

on \( B_i \times B_j \times B_k \times B_l \times B_m \times B_n \).

**Proof:** The proof directly follows from [Theorem 2, 7].

**Lemma 1:** There exists \( \zeta \in R_{+} \) such that

\[
|F_e| < \zeta
\]

on \( B \times B \times B \times B \times B \times B \).

**Proof:** It is not hard to see that choosing

\[
\zeta \geq |E|^{-1} \begin{bmatrix} \rho \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |Y_{ud} \delta| \\ m_x \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |N_{uv} \delta| \end{bmatrix}
\]

implies

\[
|F_e| \leq |E|^{-1} \begin{bmatrix} \rho \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |Y_{ud} \delta| \\ m_x \Delta x + |e_v| + 2u_a \sum_{i=1}^\infty |N_{uv} \delta| \end{bmatrix} \leq \zeta
\]

on \( B \).

The following Theorem gives an LMI formulation of the Problem 1:

**Theorem 1:** Consider (1) and (2) under (5) and (6) and Propositions 1 and 2. Let \( \Omega = \{ \{e_x, e_y\} \in R^4 : \chi^T P_k + a e_a^2 < 1 \} \). Suppose that i) \( \Omega \subset B \); ii) there exist \( \tilde{P} = \tilde{P}^T > 0 \) and \( \tilde{K} \) such that

\[
\text{Sym} \left[ A_{ijkl} P_k \tilde{G} \right] < 0
\]

(9)

\[
E_k P_k^T < \Delta_k^2
\]

(10)

\[
E_k^T P_k^T < \Delta_k^2
\]

(11)

\[
\left| \Delta_k^2 \right| \tilde{K} \leq 0
\]

(12)

for all \( \{i_1, i_2, i_3, i_4\} \in L \times L \times L \times L \). Then, for \( \{e_x, e_y\} \in \Omega \), the null space of (1) and (2) under (5) and (6) asymptotically converge to zero as \( t \to \infty \). In this feasible case, \( P = \tilde{P}^T \) and \( K = \tilde{K} P_k^T \).

**Proof:** Consider a Lyapunov function

\[
V(e_x, e_y) = \chi^T P_k + a e_a^2
\]

(9)

(10)

(11)

(12)
From Proposition 3, we see that
\[
\dot{V}_{i,(7),(8)} = \sum_{i=1}^{4} \sum_{j=i}^{4} \sum_{k=i}^{4} \sum_{l=j}^{4} \theta_{i,j} \theta_{j,k} \theta_{k,l} \text{Sym}(x^T P A_{i,j,k,l} + GK) x \\
+ 2x^T P F_2 (e_x, e_y, e_z, r) e_u - 2\sigma e_u^2
\]
on \mathcal{R} \times \mathcal{R}. Because it is true that by congruence transformation and definitions \( \tilde{P} = P^{-1} \) and \( \tilde{K} = KP^{-1} \), LMI (9) \( \Rightarrow P(A_{i,j,k,l} + GK) < 0 \) on \( (i,j,k,l) \in \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \), there exists \( Q = Q^T > 0 \) such that
\[
\dot{V}_{i,(7),(8)} < -x^T Q x + 2x^T P F_2 (e_x, e_y, e_z, r) e_u - 2\sigma e_u^2.
\]
Also, from Lemma 1 on \( R \times R \times R \times R \), we see that
\[
\dot{V}_{i,(7),(8)} < -x^T Q x + 2x^T P F_2 (e_x, e_y, e_z, r) e_u - 2\sigma e_u^2 = \begin{bmatrix} x \end{bmatrix}^T \begin{bmatrix} -Q & \zeta P \\ \zeta P^T & -2\sigma \gamma \end{bmatrix} \begin{bmatrix} x \\ e_u \end{bmatrix}
\]
Here, it can be shown that by Schur complement,
\[
\dot{V}_{i,(7),(8)} < 0 \iff \begin{bmatrix} \zeta & \gamma \gamma P^T - Q \end{bmatrix} > 0
\]
Choosing \( a \in R \) implies that the closed-loop system (7) and (8) is asymptotically stable on \( \Omega \subset \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \). Now, we are in a position to derive LMI conditions to guarantee \( \Omega \subset \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \). It can be shown that by Schur complement,
\[
\begin{bmatrix} x^T & e_u \end{bmatrix} \Omega \Rightarrow x^T P x < 1 \Rightarrow \chi x^T < P^{-1}
\]
and \( x^T x < P^{-1} \) implies \( x^T E P^{-1} F E^T x < \), \( x^T F E^{-1} F E^T x < \), and \( x^T K_0 x < K_0^{-1} x^T K_0^{-1} x < \). Thus, if LMI\( s (10), (11), \) and (12) hold, then \( \Omega \subset \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \). Consequently, if LMI\( s (9), (10), (11), \) and (12) hold, then for \( a \in \mathcal{R} \) \( \Omega \subset \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \times \mathcal{R} \), we know that the asymptotic stability of (7) is ensured if its nominal system
\[
\Sigma': \begin{bmatrix} \dot{x} \\ \dot{e}_x \\ \dot{e}_y \\ \dot{e}_z \\ \dot{r} \end{bmatrix} = (P_1 (e_x, e_y, e_z, r) + GK) x
\]
and (8) are asymptotically stable.

Remark 2: In [7], the control input \( \kappa \) is the rudder angle and on \( 1/\nu \) and thereby, \( u = 0 \) may make the given UUV unstable. Contrary to [7], the proposed approach does not have this problem since (5) is independent on \( u \).
Δ_v = 10, Δ_r = 1, and Δ_θ = 0.2374, i ∈ I_v, we have

\[
P = 10^3 \begin{bmatrix} 6.2091 & 1.2391 & 2.5489 \\ 1.2391 & 0.3603 & 0.6454 \\ 2.5489 & 0.6454 & 1.2037 \end{bmatrix}, \quad K = \begin{bmatrix} -51.3974 & -9.5864 & -22.3875 \\ 51.3974 & 9.5864 & 22.3875 \\ -51.3974 & 9.5864 & 22.3875 \end{bmatrix}
\]

Figs. 1-10 show the simulation results when γ = 10 in (6) and \((x(0), y(0), \psi(0), u(0), v(0), r(0)) = (0, 200, 0, 3, 0, 0)\). In this simulation, the control input \(|\delta|\) is limited to 0.2374. Figs. 1-5 demonstrate the trajectories \((x, y)\) and the time responses of \((e_x, e_y, e_r, e_r)\) of the UUV (1) and (2) under the proposed controller (5) and (6), respectively. Figs. 6-10 provide its control inputs. From these figures, UUV tracks \((x_k, y_k), k \in I_0\)

Fig. 4 The time response of \(v\).

Fig. 5 The time response of \(r\).

Fig. 6 The control input \(\delta_x\).

Fig. 7 The control input \(\delta_r\).

Fig. 8 The control input \(\delta_r\).

Fig. 9 The control input \(\delta_r\).

Fig. 10 The control input \(\zeta\)
successfully while keeping \( u = u_x = 3 \) under the proposed controller (5) and (6). Moreover, we know the asymptotic convergence of \( \| e \|, \| v \|, \) and \( \| w \|. \)

4. Conclusions

This paper has proposed an LMI-based design approach to waypoint tracking problem for a class of large UUVs while maintaining its constant surge speed via feedback controls. The proposed results build on the X-stern configuration, rather than cruciform-stern one, and ensure its asymptotic stabilization. The validity of theoretical claims has been successfully checked by the numerical simulation.

Appendix 1

In this paper, we use hydro coefficients and parameters of LIG Nex1 LDUUV model. The coefficients are obtained by CFD and empirical formulations based on hull geometry.

\[ m = 7500, \quad I_z = 27081.3, \quad x_y = 0, \quad L = 6.5, \quad u_y = 3, \]
\[ X_C = -157.712, \quad X_u = -62.0022, \quad X_v = 515.6301, \]
\[ X_{a,u} = -5.6299 \times 10^3, \quad X_{a,v} = -228.0492, \quad Y_{a,u} = -2.8612 \times 10^3, \]
\[ Y_{a,v} = 417.3126, \quad Y_{a} = -2.9887 \times 10^3, \quad Y_{v} = -3.1968 \times 10^3, \]
\[ Y_{u} = 2.7037 \times 10^4, \quad Y_{u,v} = -1.3259 \times 10^3, \quad Y_{u} = -591.0686, \]
\[ Y_{a,u} = 591.0686, \quad Y_{a,v} = 591.0686, \quad Y_{a} = -591.0686, \]
\[ N_C = 417.3126, \quad N_{y} = -9.0802 \times 10^3, \quad N_{v} = -1.1884 \times 10^4, \]
\[ N_{u,v} = 6.9397 \times 10^3, \quad N_{u} = -2.1449 \times 10^3, \quad N_{u,v} = -1.7355 \times 10^4, \]
\[ N_{a,u} = 1.4740 \times 10^3, \quad N_{a,v} = -1.4740 \times 10^3, \]
\[ N_{a} = -1.4740 \times 10^3, \quad N_{a,u} = 1.4740 \times 10^3. \]

Appendix 2

\[ \theta_{11} = \frac{\sin e_y}{\cos \theta_{x} \cos \theta_{y}}, \quad \theta_{12} = \frac{a_{12}}{a_{11} - a_{12}}, \quad \theta_{21} = 1 - \theta_{11}, \quad \theta_{22} = 1 - \theta_{12}, \]
\[ \theta_{31} = \frac{\| v \| - a_{22}}{a_{11} - a_{12}}, \quad \theta_{32} = 1 - \theta_{31}, \quad \theta_{41} = 1 - \theta_{31}, \quad \theta_{42} = 1 - \theta_{32}. \]

References


and control of ships, Marine Cybernetics, 2002.


저 자 소 개

김 도 완 (Do Wan Kim)
He received the B.S., M.S., and Ph.D. degrees from the Department of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2002, 2004, and 2007, respectively. He was a Visiting Scholar with the Department of Mechanical Engineering, University of California, Berkeley. In 2009, he was a Research Professor with the Department of Electrical and Electronic Engineering, Yonsei University. Since 2010, he has served on the faculty in the Department of Electrical Engineering, Hanbat National University.

김 문 환 (Moon Hwan Kim)
He received B.S. and M.S. degree in Yonsei University in 2004 and 2006, respectively. In 2006, he joined the Naval Academy of Republic of Korea as a lecturer and in 2009. From 2009 to present, he has working at LIG Nex1. His research interest includes an artificial intelligence and AUV system.

박 호 규 (Ho Gyu Park)
He received B.S and M.S. Degree in Myungji University in 1987 and 1989, respectively. From 1992 to present, he has working at LIG Nex1 as principal research engineer. His research interest includes an underwater guidance system and AUV autonomous control system.

김 태 영 (Tae Yeong Kim)
He received B.S and M.S. Degree in Kyungpook National University in 1985 and 1987, respectively. In 2009, he received Ph. D. degree in mechatronics engineering in Sungkyungkwan University. From 1987 to present, he has working at LIG Nex1. Currently, He is Director of Maritime Dept. His research interest includes underwater guidance weapon system and AUVs.