From the Automatic Control of Vessels Designed for Offshore Operating Conditions to the Automatic Control of large Barge Convoys in a River/Canal: Lessons Learned

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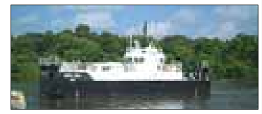
Evolution

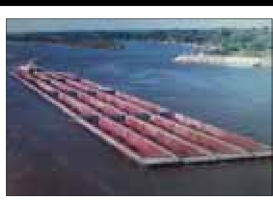
- 2001 saw the introduction of the Bow Steering Module using Voith propulsion
- Its main purpose is to generate steering forces at the bow, so that the entire group can be maneuvered in narrower channels with larger convoys.



Bridges & Push Boat

Convoys

Convoys



The River

The length of the Paraná-Paraguay river to source of longest tributary is approx.2,795 miles or 4,700 km

Rio Tinto Project

To make this method of river navigation to be possible, Symmetry developed and supplied a solution consisting of:

- **Customized** IDP for river navigation.
- VMS (*Vessel Management System*) integrated with the IDP.
- Telemetry system via radio for remote control and alarm monitoring.
- Remote video system via radio
- Simulator for training and tests
- Instrumentation of a conventional convoy for comparative tests.

The Mathematical Model

- The Hull Hydrodynamics

$$X_{H_{LOW}} = X_{uu_{LOW}} u^2 + X_{uvr_{LOW}} \frac{u}{|u|}|v||r|$$

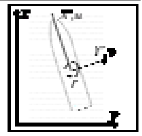
$$Y_{H_{LOW}} = Y_{vu_{LOW}} vu + Y_{ru_{LOW}} ru + Y_{vv_{LOW}} ru + Y_{vv_{LOW}} v|v| + Y_{rr_{LOW}} r|r|$$

$$N_{H_{LOW}} = N_{vu_{LOW}} vu + N_{ru_{LOW}} ru + N_{v|v|_{LOW}} v|v| + N_{rr_{LOW}} r|r|$$

$$X_{H_{LOW}} + X_{prop} + X_{rud} + X_{env} = m(\dot{u} - vr - x_G r^2)$$

$$Y_{H_{LOW}} + Y_{prop} + Y_{rud} + Y_{env} = m(\dot{v} + ur + x_G r^2)$$

$$N_{H_{LOW}} + N_{prop} + N_{rud} + N_{env} = (I_z + m x_G^2)\dot{r} + m x_G(\dot{v} + ur)$$



Coefficients obtained from IPT & MARIN

The Observer and the Controller

$$\dot{\hat{x}} = \hat{u}\cos(\psi) - \hat{v}\sin(\psi) + k_1\tilde{x} + k_2\tilde{y} + k_3\tilde{\psi}$$

$$\dot{\hat{y}} = \hat{u}\sin(\psi) + \hat{v}\cos(\psi) + k_4\tilde{x} + k_5\tilde{y} + k_6\tilde{\psi}$$

$$\dot{\hat{\psi}} = \hat{r} + k_7\tilde{x} + k_8\tilde{y} + k_9\tilde{\psi}$$

$$\dot{\hat{u}} = -a_1\hat{x} - a_2\hat{u} + b_1\tau_1 + k_{10}\tilde{x} + k_{11}\tilde{y} + k_{12}\tilde{\psi}$$

$$\dot{\hat{v}} = -a_3\hat{y} - a_4\hat{v} - a_5\hat{r} + b_2\tau_2 + b_3\tau_3 + k_{13}\tilde{x} + k_{14}\tilde{y} + k_{15}\tilde{\psi}$$

$$\dot{\hat{r}} = -a_6\hat{y} - a_7\hat{v} - a_8\hat{r} + b_2\tau_2 + b_3\tau_3 + k_{16}\tilde{x} + k_{17}\tilde{y} + k_{18}\tilde{\psi}$$

Observer based on Lyapunov Stability Theory

$$\begin{bmatrix}\tau_1\\ \tau_2\\ \tau_3\end{bmatrix} = -S^{-1}\begin{bmatrix} c_2 z_2 + \phi_2 + d_2(\omega_{21}^2 + \omega_{22}^2 + \omega_{23}^2 + \omega_{26}^2) z_2 + z_1 \\ c_4 z_4 + \phi_4 + d_4(\omega_{41}^2 + \omega_{42}^2 + \omega_{43}^2 + \omega_{46}^2) z_4 + z_3 \\ c_6 z_6 + \phi_6 + d_6(\omega_{61}^2 + \omega_{62}^2 + \omega_{63}^2) z_6 + z_5 \end{bmatrix}$$

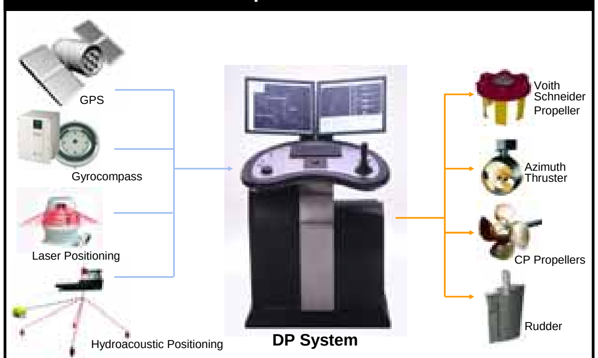
$$S = \begin{bmatrix} b_1\cos\psi & -b_2\sin\psi & -b_3\sin\psi \\ b_1\sin\psi & b_2\cos\psi & b_3\cos\psi \\ 0 & b_4 & b_5 \end{bmatrix}$$

Control Law – Backstepping

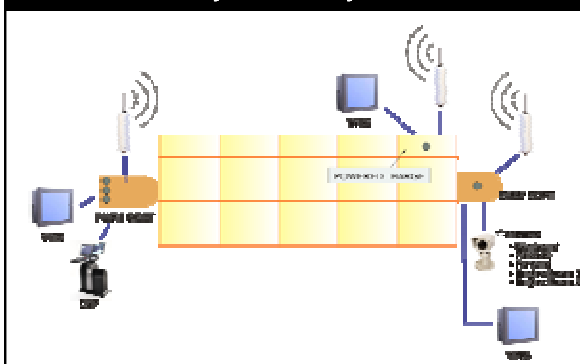
Symmetry's IDP

- Algorithm enables the system to self-calibrate continually to more accurately maintain position under a wider range of weather conditions.
- Affordable.
- Navigation software included.
- User-friendly interface.

Operation

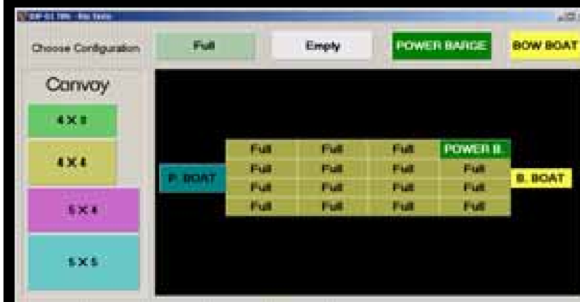


System Layout



VMS (*Vessel Management System*)

Customized Tools



Plotting

Desk Simulator

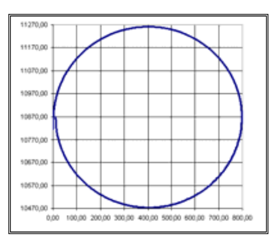
Compact DP simulator, used for personel training.

Integrated Simulator

DP Simulator integrated with the ship bridge simulator at the Brazilian Navy Training Center CIAGA (RJ).

Results

Tuning Circle Simulation of 30 Barges, 5 meters draught using BSM

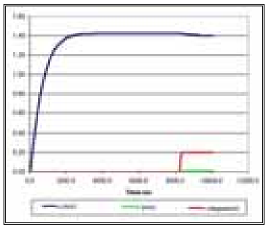


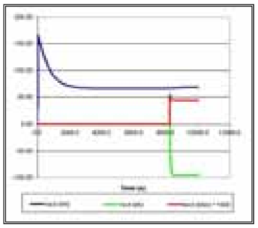
DP Simulator

DYNASIM

Results

- Values of u,v and r of 30 barges vs. Time
- Values of Moment and Forces x and y vs. Time





Benefits & Characteristics

Tests of this new concept demonstrated significant advantages over traditional convoys.

- Remote controle of the BSM.
- Controls unified in a single joystick.
- Pivot point moved to the center of the convoy.
- Safely increased the number of barges.
- Improve the transported weight/fuel used ratio
- Improve the stopping and turning capacity.
- Flexibility of having an additional push boat to assist during convoy assembly.

Conclusions

- The waterway transportation sector, despite its problems and bottlenecks, is continually seeking alternatives to improve its operations.
- In the aim of increasing efficiency, safety and reducing costs, the sector is modernizing and acquiring new technology.
- The Dynamic Position control system for large barge convoys is one of the highlights of the new technology.
- This innovation may make development in the Brazilian waterway transportation sector feasible, as it allows for navigational safety and greater flexibility in transport and distribution not only for mined products but for petroleum and its derivatives as well.

Thank you!

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