A Wave Simulator and Active Heave Compensation Framework for Demanding Offshore Crane Operations

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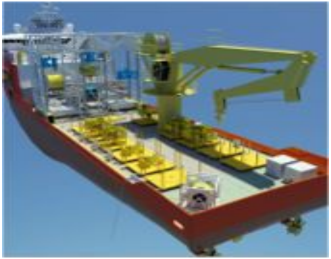
Summary

Current maritime crane control architecture

Low control flexibility and non-standardisation are two crucial issues:

- relatively simple control interfaces;
- array of levers, throttles or buttons are used to operate the crane joint by joint;
- each input device can normally control only one specific crane model.

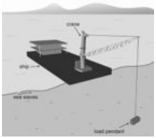
When considering working efficiency and safety, this kind of control is extremely difficult to manage and extensive experience with high control skill levels is required of the operators[1].

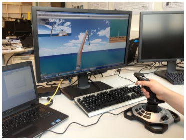


[1] Filippo Sanfilippo et al. "A Universal Control Architecture for Maritime Cranes and Robots Using Genetic Algorithms as a Possible Mapping Approach". In: *Proc. of the IEEE International Conference on Robotics and Biomimetics (ROBIO), Shenzhen, China*. 2013, pp. 322–327.

Motivation factors

- More flexible and reliable control approaches are needed. Several research groups are investing resources in this direction.
- However, testing new control methods in a real setup environment is very difficult because of the challenging work-space in which maritime cranes are operated.
- Due to the challenging crane operational scenario in real applications, several studies have been performed by using a computer-simulated environment[2,3].





Disadvantages of a computer-simulated environment:

- A simulation approach is always limited when compared to a realistic experimental setup.

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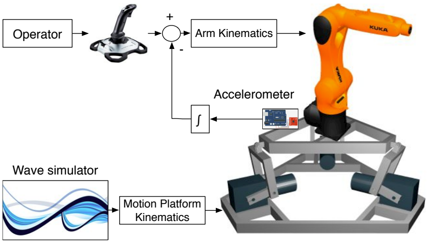
[2] Jörg Neupert et al. "A heave compensation approach for offshore cranes". In: *Proc. of the IEEE American Control Conference, Seattle, Washington, USA*. 2008, pp. 538–543.

[3] Filippo Sanfilippo et al. "Flexible Modeling And Simulation Architecture For Haptic Control Of Maritime Cranes And Robotic Arm". In: *Proc. of the 27th European Conference on Modelling and Simulation (ECMS), Aalesund, Norway*. 2013, pp. 235–242.

A wave simulator and active heave compensation framework



The framework is highly modular and open-source:

- Modular Design;
- Modular Mechanics;
- Modular Hardware;
- Modular Software.

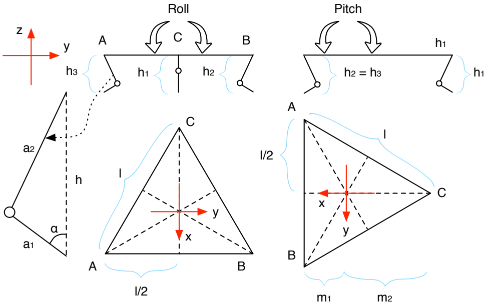
Testing alternative control algorithms in a realistic and safe laboratory setup:

- The system is composed of an industrial robot, the *Kuka KR 6 R900 SIXX (KR AGILUS)* manipulator, and of a motion platform with three DOF.
- The motion platform allows the simulation of wave impacts, while the robotic arm can be manoeuvred by the user.
- An accelerometer is adopted in order to monitor the wave contribution.

Not only an engineering tool but mostly a scientific tool!

- A framework that can be used to discover new ways of controlling maritime cranes.

Motion platform kinematics



$$h = a_1 \cos(\alpha) + \sqrt{a_2^2 - a_1^2 \sin^2(\alpha)} \quad (1)$$

$$\Delta(h_2, h_3) = \sin(\phi) l \quad (2)$$

$$\phi = \frac{\arcsin(\Delta(h_2, h_3))}{l} \quad (3)$$

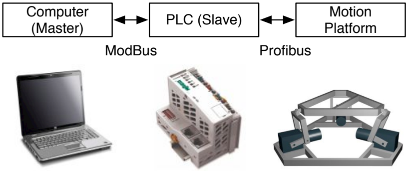
$$h_2 = h_3 = -\sin(\theta) m_1 \quad (4)$$

$$h_1 = \sin(\theta) m_2 \quad (5)$$

$$\theta = \arcsin(\frac{\Delta(h_2, h_3) - h_1}{m_1 + m_2}) \quad (6)$$

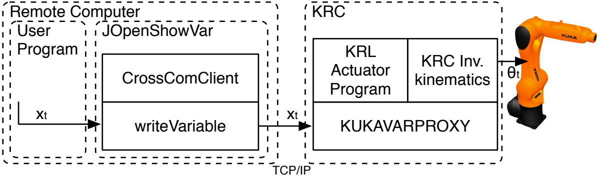
- It is a type of parallel robot that incorporates three DOFs. It consists of three arms connected to universal joints at the top base. Each joint is actuated by a motor.
- The rotation range of each joint is limited to 125° which corresponds to the joint pointing straight up, and the corresponding platform corner to have its maximum height.

Motion platform interface



- In order to simulate a realistic application scenario, the control system that actuates the motion platform is independent from the control system that operates the robotic arm.
- The motion platform is controlled by using a hardware platform based on a commercial *Programmable Logic Controller* (PLC).
- By using the *Modbus* protocol, a master-slave pattern is set up with the controller acting as a master and the PLC as a slave.
- The three axes of the motion platform are driven by DC motors (203V). The motors are interfaced to a motor controller.
- A programmable power supply board is used in order to avoid buying costly *H bridge* circuits. This board can be remotely controlled from the PLC via Profibus.
- The motor revolution is controlled by means of inverters.

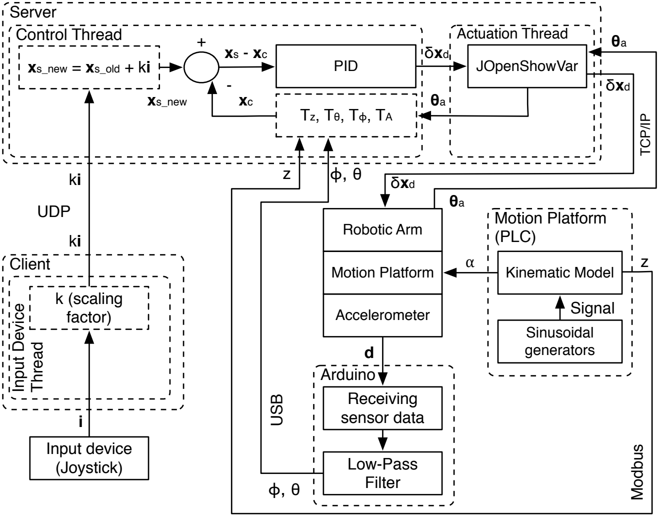
Robotic arm interface



- The robot can be operated by the user by means of a standard joystick. In order to efficiently control the robot, the open-source cross-platform communication interface provided by *JOpenShowVar*[4] is used. This choice is motivated by the fact that *JOpenShowVar* allows researchers to implement alternative control algorithms according to current needs.
- It is a client-server architecture with *JOpenShowVar* running as a client on a remote computer and *KUKAVARPROXY* acting as a server on the *Kuka Robot Controller* (KRC). *JOpenShowVar* locally interacts with the user program and remotely communicates with the *KUKAVARPROXY* server via *TCP/IP*.

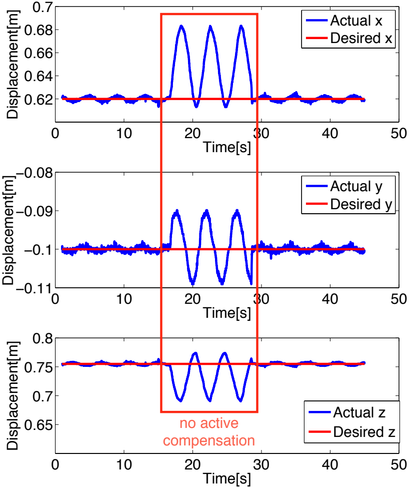
[4] F. Sanfilippo et al. "JOpenShowVar: an Open-Source Cross-Platform Communication Interface to Kuka Robots". In: *Proc. of the IEEE International Conference on Information and Automation (ICIA), Hailar, China*. 2014, pp. 1154–1159.

Integrated control system



Experimental results

Experimental results



Conclusion and future work

A wave simulator and active heave compensation framework for demanding offshore crane operations:

- It makes it possible to reproduce in a laboratory setup the challenging operation scenario of controlling offshore cranes.
- The system is built on open-source software and hardware and it can be used for testing different control algorithms as well as for training purposes.

Future work:

- Different control algorithms may be tested as alternatives to the standard kinematic method[5].
- Integration of the proposed system with the flexible maritime crane architecture that we recently developed[6].
- Standardisation process of the proposed framework to make the system more reliable for both the industrial and the academic practice.

[5] Filippo Sanfilippo et al. "A mapping approach for controlling different maritime cranes and robots using ANN". In: *Proc. of the IEEE International Conference on Mechatronics and Automation (ICMA), Tianjin, China*. 2014, pp. 594–599.

[6] F. Sanfilippo et al. "Integrated Flexible Maritime Crane Architecture for the Offshore Simulation Centre AS (OSC)". In: *submitted to the IEEE Journal of Oceanic Engineering* (2015).

Thank you for your attention

Official repository and support:

- The official repository is available on-line at `https://github.com/aauc-mechlab/WaveSimulator`, along with several detailed class diagrams, all the mechanics, hardware schematics and demo videos.
- F. Sanfilippo, Department of Maritime Technology and Operations, Aalesund University College, fisa@hials.no.