Return to Session Directory

DYNAMIC POSITIONING CONFERENCE
October 12-13, 2010

SENSORS SESSION

Low noise motion measurements and accurate transformation of acceleration over long lever arms on large vessels – method, test results and opportunities

By Finn Otto Sanne, Terje Bogfjellmo, Morten Lund Bjarnar, Arne Rinnan

Kongsberg Seatex AS
Trondheim, Norway

Abstract

Low noise motion measurements and accurate transformation of acceleration over long lever arms on large vessels – method, test results and opportunities

Manual or automated operations rely on precise and reliable motion measurements. Operations can be improved and the operational window for the operation can be extended by better utilization of such measurements. Operations can potentially be performed in rougher weather conditions than earlier without exceeding safety margins.

Acceleration measurements are important in order to determine forces (Force=Mass*Acceleration) acting on critical points in a system, like modules or humans on deck. Better operational control and better control of safety levels is achieved with availability of acceleration data.

This paper presents a new method for transformation of acceleration over longer distances on a rigid body. Traditionally a number of accelerometers or motion sensors have to be mounted close to any point where acceleration is needed on board a vessel. This is not always feasible and might also be prohibitive due to cost considerations. The new method offers a much better utilization of high precision motion sensors. This also opens for establishing new operational procedures to increase efficiency and improve safety.

Results from an operating vessel verify the improvement of the new method compared with traditional methods. These data and results are presented and analyzed in the paper.

The new method can be utilized on a single vessel by generating alarms when acceleration limits are exceeded. Today operational constraints usually are derived from numerical simulation of vessel responses based on input of environmental conditions. Accurate transformation of acceleration to the points critical to the operation will represent a direct measurement of the vessel motion and provide an excellent supplement to the constraints derived from the environmental conditions.

Figure 1 This 120 meter long construction support vessel (CSV) named Skandi Seven is a typical vessel for the discussed operations

Introduction

On a vessel there are many points that are of interest to get measurements from, like:

- The helideck centre for helicopter operations
- The ROV launch and recovery position over the side of the vessel prior to launch or recovery of the ROV
- The crane tip during crane operations
- The location of modules on the cargo deck prior to release of sea fastening
- The moonpool during module handling or diver operations
- The davits prior to launch of the Man-Over-Board boat

However, it is too costly and complex to install a sensor in each of these points and therefore there are normally no measurements for available onboard to assist under the operations.

The overall operational constraints are often a combination of environmental conditions and associated motion responses. An example of operational criteria is shown in Table 1. The operational criteria in this table shows this combination of environmental limitation gives as significant wave height (Hs) and wave period (Tp) together with motion responses as linear accelerations in three directions.

Cond. No.	Operation	Environmental Conditions	Accelerations (Moonpool Centre) 3 hours duration		
			Heave (m/s^2)	Sway (m/s^2)	Surge (m/s^2)
1	Well intervention operations	Hs=4.0m Tp=12.0s	0.88	0.39	0.98
2	Module deployment	Hs=3.0m Tp=9.7s	0.69	0.29	0.69
3	Horizontal skidding of modules	Hs=5.0m Tp=11.0s	1.18	0.49	1.18
4	Subsea support and construction	Hs=4.0m Tp=12.0s	0.88	0.39	0.91

Table 1 **Shows typical operations and associated maximum environmental conditions and accelerations for safe operation**

The environmental conditions are available from oceanographic buoys, wave radars or meteorological forecasts, but are the motion responses available onboard? How to ensure that every operation requirement has been fulfilled unless both environmental conditions and acceleration measurements are available?

In the following example we will show the challenges to get good acceleration measurements in other points that where the motion sensor (MRU) is mounted. In this examples we want a heave acceleration measurement available in the crane tip, see Figure 2.

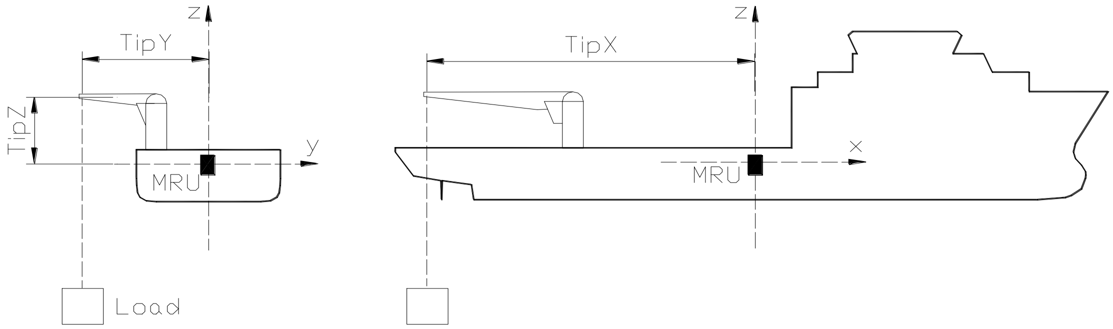


Figure 2 Shows the crane tip location and the distance from the MRU to the crane tip (TipX, TipY, TipZ)

To be able to transfer the heave motion from the MRU location to another point we need to know:

1. The relative offset coordinates (TipX, TipY, TipZ) from the MRU location to the location we want to calculate the heave motion, the crane tip in this example.
2. The roll angle, angular velocity and angular acceleration
3. The pitch angle, angular velocity and angular acceleration
4. The heave motion in the MRU location (position, velocity and acceleration)

In Table 2 is shown the transformation algorithm to transform the heave motion from the MRU to the crane tip. The real heave motion of the crane tip is calculated as crane tip position (TipPos), velocity (TipVel) and acceleration (TipAcc). Structural elasticity etc. in the vessel and crane are not taken into account in this algorithm.

Transformation algorithm			Result
TipPos	=	Heave - cos(Roll)*sin(Pitch)*TipX + sin(Roll)*TipY - (1 - cos(Roll)*cos(Pitch))*TipZ	Okay to calculate
TipVel	=	HVel + RoVel*(sin(Roll)*sin(Pitch)*TipX + cos(Roll)*TipY - sin(Roll)*cos(Pitch)*TipZ) - PiVel*(cos(Roll)*cos(Pitch)*TipX + cos(Roll)*sin(Pitch)*TipZ)	Okay to calculate
TipAcc	=	HAcc + RoVel*RoVel*(cos(Roll)*sin(Pitch)*TipX -sin(Roll)*TipY - cos(Roll)*cos(Pitch)*TipZ) + PiVel*RoVel*(2*sin(Roll)*cos(Pitch)*TipX + 2*sin(Roll)*sin(Pitch)*TipZ) + PiVel*PiVel*(cos(Roll)*sin(Pitch)*TipX - cos(Roll)*cos(Pitch)*TipZ) + RoAcc*(sin(Roll)*sin(Pitch)*TipX + cos(Roll)*TipY - sin(Roll)*cos(Pitch)*TipZ) - PiAcc*(cos(Roll)*cos(Pitch)*TipX + cos(Roll)*sin(Pitch)*TipZ)	Problematic due to inaccuracy in roll and pitch angular acceleration

Table 2 Shows the transformation algorithm for heave position, velocity and acceleration from the MRU location to the crane tip. Marked yellow is the problematic roll and pitch angular measurements in this algorithm that generate noise in the calculation of crane tip heave acceleration (TipAcc)

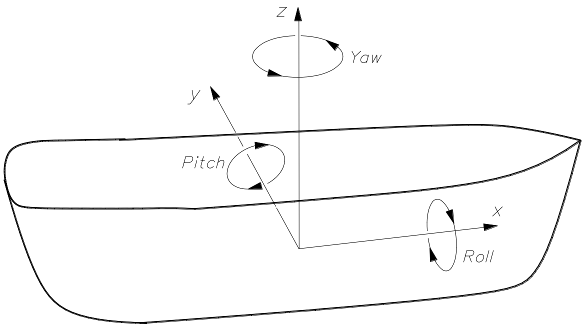


Figure 3 The defined positive rotation angles used in the transformation algorithm

The challenge is to have reliable angular acceleration measurements available for the transformation. Angle and angular velocity measurements are often easily available from components within a motion sensor (contents three angular rate sensor and three linear accelerometers), but angular acceleration is normally achieved by deriving the angular rate signal. This generates a noisy angular acceleration signal which again leads to a noisy TipAcc calculation when the offset coordinate values increases (TipX, TipY, TipZ).

In the following plots typical angular and linear measurements are shown when the motion sensor:

- Outputs data in its mounting location
- Transfer's the heave motion 10 meters away from it mounting location

Figure 4 shows the roll angle, roll angular acceleration and heave acceleration measurements from an MRU in its mounting location for a typical vessel motion. For this dataset there is no transformation of the heave acceleration measurements. This figure illustrates the roll acceleration measurement characteristics from a motion sensor, and is in fact quite noisy. However, the heave acceleration measurement is within an acceptable accuracy level for checking whether the motion is within the operation criteria or not. The heave acceleration for this dataset has a noise level of approximately 0.03 m/s^2. In Table 1 the lowest heave acceleration limit is 0.69 m/s^2 which are much higher than the noise level measured.

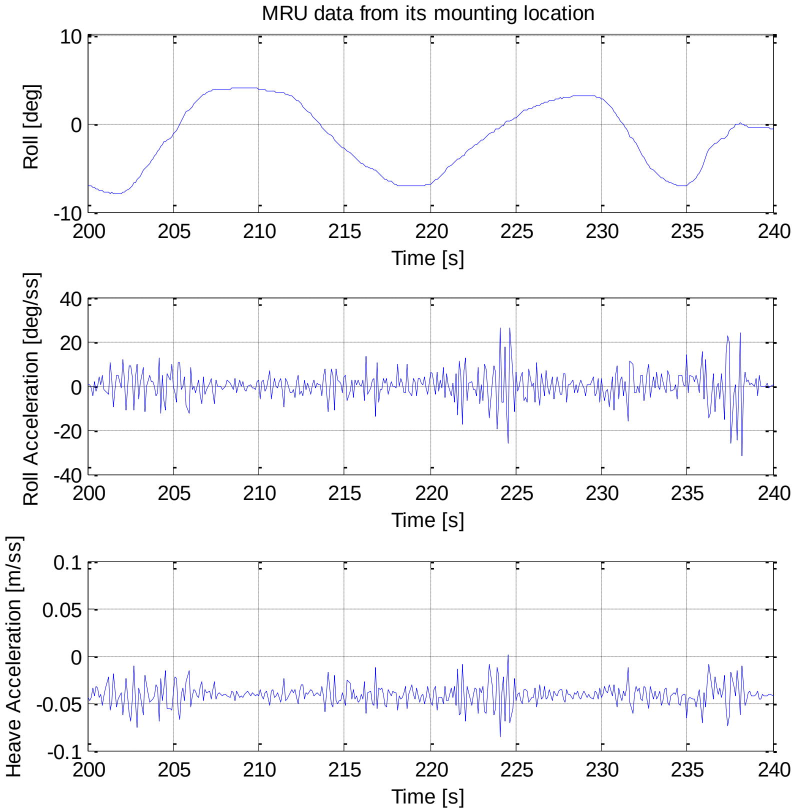


Figure 4 Shows the roll angle, angular acceleration and heave acceleration measurements from an MRU in its mounting location for a typical vessel motion

Figure 6 and Figure 7 shows data from a motion sensor where the heave motion is transferred 10 meters away from its mounting location (10 meter offset).

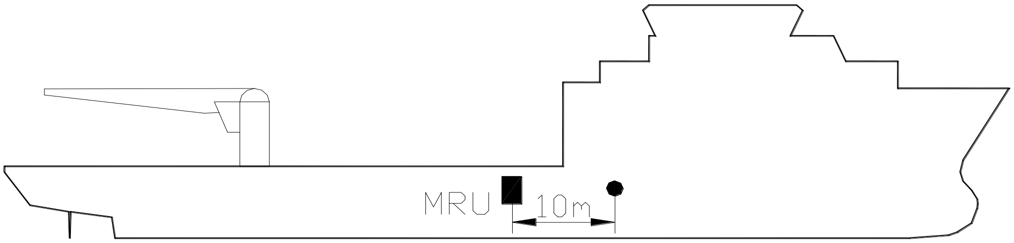


Figure 5 Shows a 10 meter offset from the motion sensor location on a vessel

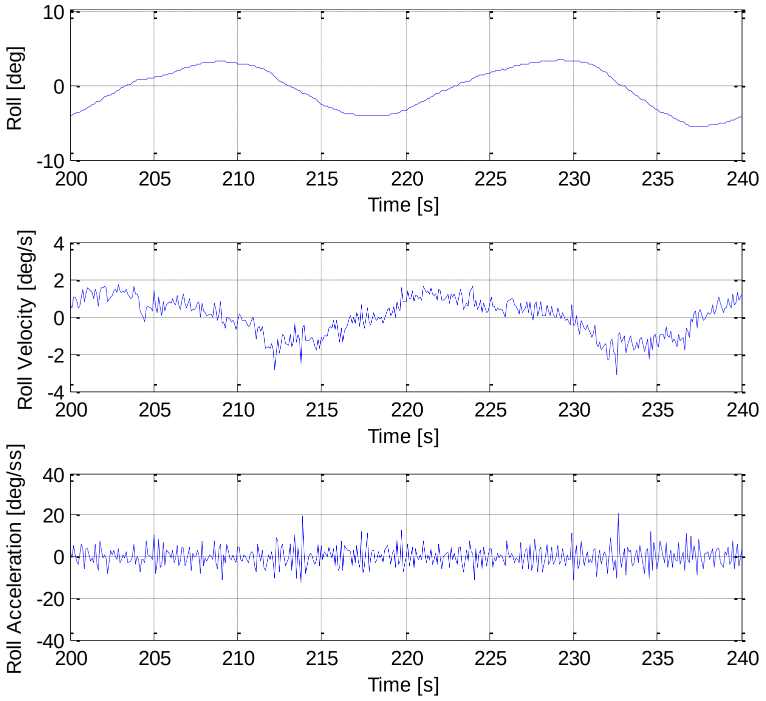


Figure 6 Shows the roll motion at the motion sensor location

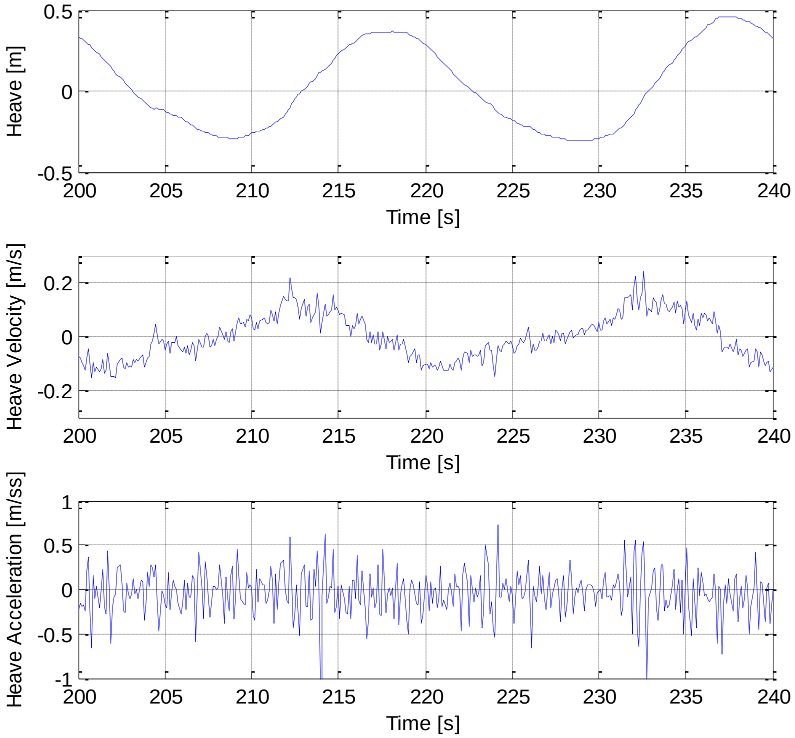


Figure 7 Shows the heave motion transferred 10 meters away from the motion sensor location

Figure 7 shows the heave motion transferred 10 meters away from the sensor location. Here it is impossible to see the real acceleration because of the noise level. The heave acceleration plot shows that the noise level is approximately 0.25 m/s^2 which are close to the heave acceleration limit in Table 1 that is given in the range 0.69 to 1.18 m/s^2. This illustrates the challenge by transferring the heave acceleration away from the motion sensor location. Even a small offset distance of 10 meters from the motion sensor location generates a large noise level in the heave acceleration measurements, and makes transformation useless for this type of application.

New developed algorithm

To improve the transformation algorithm, the following methods are available:

- One possibility is to filter the angular acceleration signal prior to the transformation. The disadvantage is then that the signal will be delayed and do not correspond with the other measurements in the dataset. This introduces inaccuracy.
- Another is to mount a network of accelerometers onboard the vessel, like two accelerometer transversal and two longitudinal, and from them determine an angular acceleration signal. This works fine if you have control of the timing from all the sensors, but is a costly method both to install and maintain.
- An easy method would be to buy an angular acceleration sensor. Unfortunately, only a few manufactures are available and the quality of the measurements is not of the preferred accuracy.
- In the M-Trans™ algorithm (patent pending) developed by Kongsberg Seatex, this is done in a totally new way.

The M-Trans™ algorithm is a vessel state estimator that estimates angular acceleration values by a predictive filter. To verify the accuracy by the M-Trans™ algorithm we have performed the following installation on a ship:

- Installed one MRU close to the helideck at the bow section
- Installed one MRU in a container on the maindeck close to the moonpool
- Transferred the surge, sway and heave measurements from the MRU at the helideck to the moonpool location where the other MRU is mounted and compared the data with the measurements from the MRU at the moonpool, and vice versa.

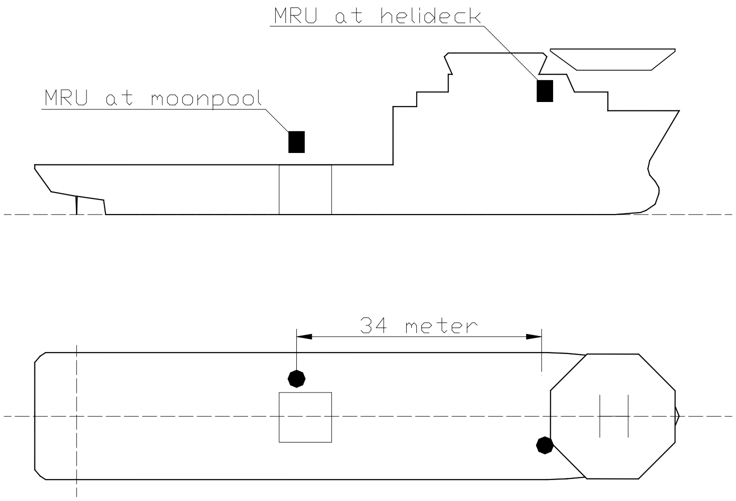


Figure 8 Shows the location of the two MRU's and the distance between them

Results from traditional transformation of acceleration measurements compared with the real motion are shown in Figure 9. This figure shows a very noisy heave acceleration measurement. In Figure 10 is shown the results by use of the new developed algorithm compared with the real motion. When transforming the motion over long distances as in this comparison (over 34 meters) some phase and amplitude errors will occur by use of the M-Trans™ algorithm. However, compared to the traditional method of transformation the result by the new algorithm is a low noise measurement and almost identical to the real motion.

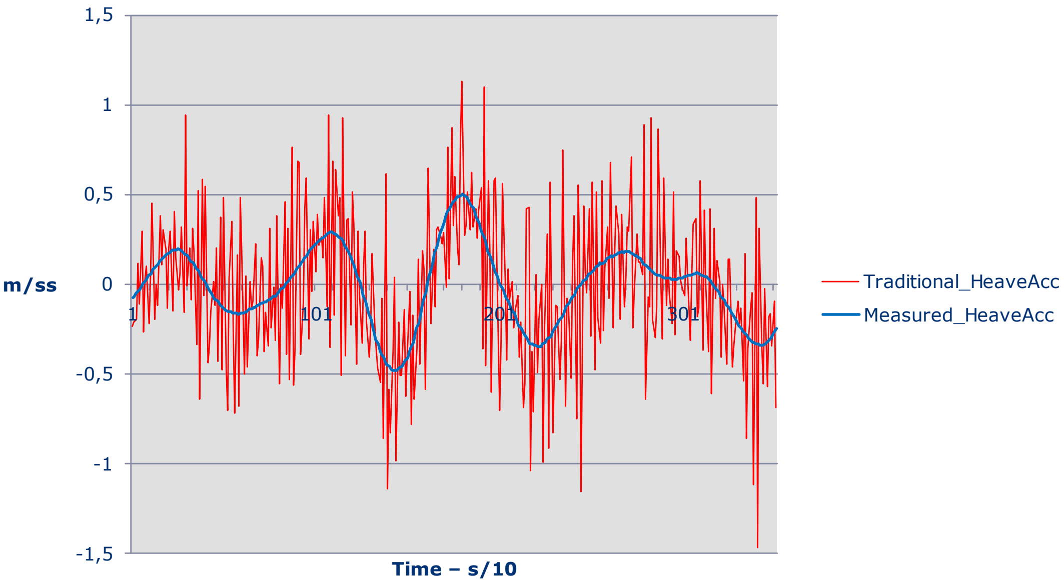


Figure 9 Show the result of a traditional transformation of acceleration measurements (red curve) together with the real motion (blue curve)

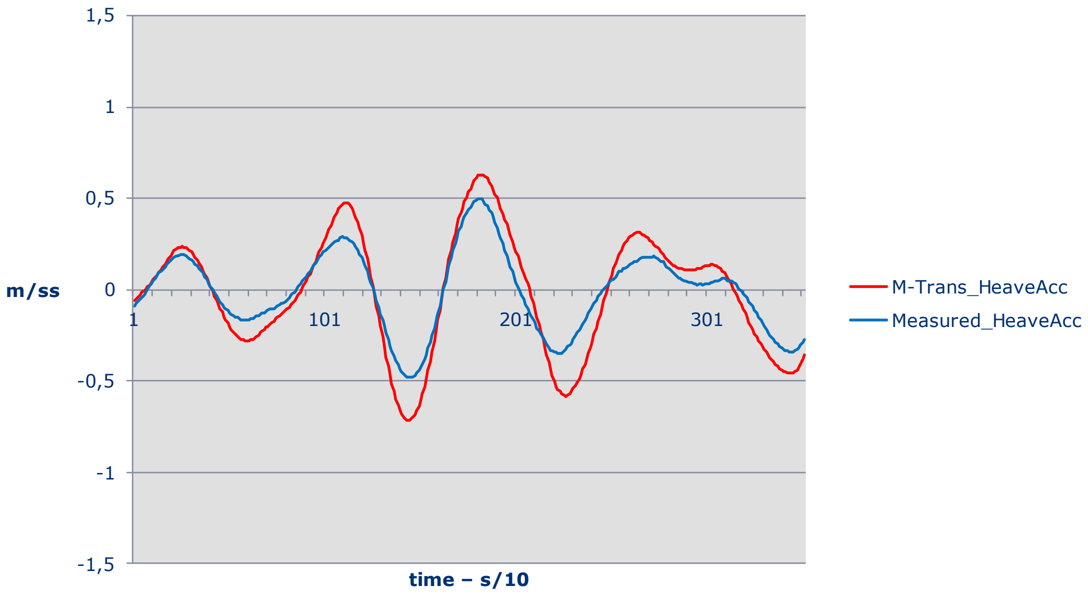
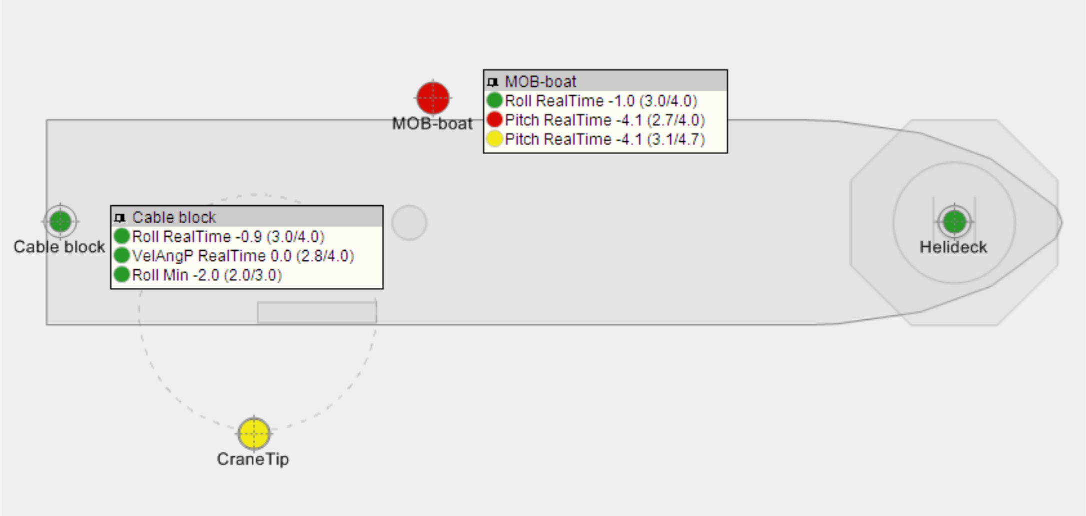


Figure 10 Shows the results by use of the M-Trans™ algorithm on the same dataset (red curve) together with the real motion (blue curve)

The M-Trans™ algorithm is implemented in the Vessel Motion Monitor (VMM 200) product from Kongsberg Seatex.

Applications

It is now possible to develop a system to monitor the motion in different point on the vessel simultaneously and give warning/alarms when certain levels are excited. An example of how this can be visualized is shown in Figure 11. This ensures a total overview of the motion conditions all over the vessel through a quick look at the screen.



MOB-boat
🟢 Roll RealTime -1.0 (3.0/4.0)
🔴 Pitch RealTime -4.1 (2.7/4.0)
🟡 Pitch RealTime -4.1 (3.1/4.7)

Cable block
🟢 Roll RealTime -0.9 (3.0/4.0)
🟢 VelAngP RealTime 0.0 (2.8/4.0)
🟢 Roll Min -2.0 (2.0/3.0)

Figure 11 Shows a number of monitoring points on a vessel and whether the movements are within the user defiend limits or not (green - within the limit, yellow - reached the warning limit, red - exceeded the limit). This screen is design protected, Norwegian Design Registration No. 081351

Typical operations where this can be an advantage is:

- Skidding of module on the cargo deck
- Offshore crane lifts
- Launch and Recovery of ROV's and MOB boats over the vessel side
- HSE aspect related to sending people out on deck or up in the mast

Operations can be improved and the operational window for the operation can be extended by better utilization of motion measurements. Operations can potentially be performed in rougher weather conditions than earlier without exceeding safety margins.

Summary

This paper has analyzed traditional transformation algorithms and shown why they cannot be used to transfer acceleration measurements to different locations on a vessel.

The M-Trans™ algorithm has demonstrated a good match of transferred heave acceleration with the real motion for the same location up to 30 meters away for the motion sensor location. Due to the fact that a ship is not 100% stiff, there will be limitations on how far away a measurement can be transferred. However, for a CSV type of vessel the M-Trans™ algorithm shows excellent results.

The operation limits shown in Table 1 are derived from numerical simulation of vessel responses based on input of environmental conditions. When the operation is performed out the offshore field only the environmental data are normally available (wave height and period). With acceleration measurements available through proper motion transformation as presented in this paper, both the environmental data and the direct measurements of the vessel motion can be used to ensure safe and efficient operations.