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(54) Method of measuring the trailing force exerted on a dredging arm during operation of a floating dredge and in particular a hopper suction dredge.

(57) Method of measuring the trailing force exerted on a dredging arm during operation of a floating dredge, in which said trailing force is derived from an algorithm using process data being measured during dredging. The following data can be applied as process data, either individually or in combination:

a) the concentration of the mixture brought up by dredging, in the suction tube;
b) the velocity of the dredged mixture in the suction tube; and
c) the pressure difference over the suction head.

With the use of a Kalman filter the relation between the actual trailing force exerted on the dredging arm and the measured pressure difference over the suction head is estimated continuously, so that the actual trailing force can be calculated.

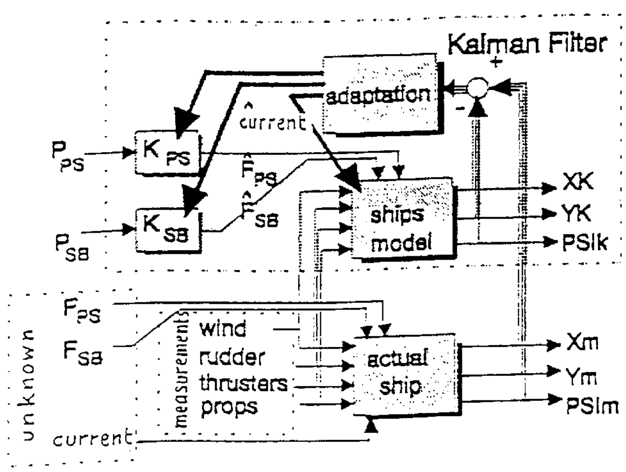

FIG. 1

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Description

The invention relates to a method of measuring the trailing force exerted on a dredging arm during operation of a floating dredge and in particularly a hopper suction dredge.

GB-A-2 242 788 describes a system for laying a cable or pipe stored in vessel onto a sea bed while using a sledge positioned on said vessel, and for measuring the tension of the cable when it enters and leaves said sledge. Obviously, such a system can not be used for measuring the trailing force exerted to a dredging arm during dredging.

At present, the known floating dredges are increasingly equipped with a "Dynamic Positioning System", or in short the DP system, with the purpose of directing the ship exactly along a certain path. This is particularly desirable when a trench is to be dredged in which an oil or gas pipe or cable should be positioned. The exactness in dredging the trench will determine the time required for the job. Obviously, it is useless to dredge away more ground than necessary, so not next to the trench and not deeper than necessary in order to prevent formation of undesired holes.

JP 07 260482 (Patent Abstracts from Japan vol. 096, no. 002, February 29, 1996) describes the use of a GPS system for specifying the position of a dredger.

However, when using the DP system one tries to measure the loads exerted on the ship, such as the influence of the wind and of the forces produced by the dreding arms. When the wind or the dredging trailing forces change, these can be responded by exerting opposite forces by means of suitable "actuators" such as propellers, rudders, bow thrusters and possible stern screws. This prevents the ship from deviating too much from its desired path. Here, it is important that disturbances are responded to even before a deviation in the ship's path can be measured.

A disturbance may also occur in the water current alongside the ship and unterneath it. This will occur in particular at the position where the dredging takes place, since due to variations in the bottom depth, the water current and direction under the keel of the ship might vary. In general, the water current can not be measured, since the instruments used with normal ships do not function properly due to disturbances caused by the dredging process.

Therefore, the current has to be estimated, which is usually done with a so-called "Kalman filter". The use of a Kalman filter is known from e.g. JP 09 014962 (Patent Abstracts of Japan, vol. 097, no. 005, May 30, 1997). In this case, said Kalman filter is used for shortening the period until the computed position of a construction vehicle converges to the actual position thereof.

With the method according to the present invention, a mathematical model of the ship to be controlled can be contained in a Kalman filter and all forces acting on the ship can be input into the filter. Said forces are derived from the wind, from the forces of the propellers, from the bow and possibly stern thrusters, from the rudder positions and from the forces exerted by the dredging arms.

With the help of said known forces, the movement and rotation of the ship is predicted and compared to the present change measured with positioning equipment such as DGPS and the compass, for example. Since the movement comparisons only lack the influence of the water current, the difference between the actual movement and rotation and the predicted movement and rotation can be used to calculate the flow. In control engineering, this is called "estimating". This estimated flow can then be used in the control algorithms to provide for that the ship will continue following the desired path accurately.

With application on floating dredges, e.g. with hopper dredges, there are forces being exerted on the ship by the dredging arm or the dredging arms, that can be in the shape of suction tubes. Said forces can be a factor 10 larger than the force required to sail. Thus, it may occur that 90% of the propulsion power is required for compensation of the forces in the dredging arms, and 10% for propulsion of the ship itself. Thus, in order to produce an accurate prediction of the movements of the ship, it is necessary to measure the forces occurring in the dredging arms as accurately as possible. To that end, one employs sensors generally incorporated in the pivots of the suction tubes. However, during dredging they disappear under water and during sailing they are hoisted on deck. Therefore, the sensors are exposed to large ambient changes and experience has shown that on average, they only have a short useful life. The sensors are expensive and thus frequent replacement is costly. With a defective sensor, the DP system will not function properly due to the relatively great influence of the suction tube.

Further, the measurements are performed at a great distance from the suction head, as a consequence of which disturbances caused by e.g. the weight of parts of the suction tube, the forces exerted on the suction tube by the hoisting cables, the pressure differences caused by the suction process and the like, should be compensated. Further the weight of the suction tube can vary due to variation in the solids concentration of the mixture brought up via the suction tube by dredging.

The object of the invention is to remove these difficulties and to that end provides for, that the trailing force exerted on a dredging arm is derived from an algorithm using process data being measured during the process of dredging.

For example, such process data are:

a) the concentration of the mixture brought up by dredging, in the suction tube;
b) the velocity of the dredged mixture in the suction tube; and

c) the pressure difference over the suction head.

During dredging, seen in time, particularly the pressure difference over the suction head appears to have the same dynamic behaviour as the tensile force being measured directly. Therefore, it would be obvious to use said differential pressure over the suction head as an alternative for the direct measurement of the trailing force. However, this causes the problem, that the pressure difference over the suction head is not only proportional to the trailing force, but also depends on the type of soil. To wit, the trailing force is proportional to the force by which the suction head is pulled across the ground, since the suction head is pressed onto the ground as a consequence of the pressure difference occurring over the suction head. Thus, with movement of the suction head, the friction force between the suction head and the ground will have to be overcome.

The pressure difference over the suction head is additionally affected by the excavating process, the mixing velocity and the concentration of the dredged mixture. Further, the trailing force is influenced by the possible mounting of teeth and water jets at the bottom of the suction head, which together should loosen the ground. Thus, the complete dredging process around the suction head is a very complex process which can not be represented aboard by simple relations, also because the data concerning the condition of the ground, and thus the composition of the mixture brought up by dredging, are not continuously available.

According to a further elaboration of the invention, when using a Kalman filter, the relation between the actual trailing force exerted on the dredging arm and the measured pressure difference over the head is estimated continuously.

The reason that the filter is able to estimate both the correct value and the previously mentioned value of the water current is that the trailing force on the dredging arm changes continuously and quick due to the specific dredging properties - in which changes from 0 to 100% can occur within a few seconds - whereas changes in the current only occur in the order of minutes to hours. Due to this difference in dynamics, the Kalman filter is capable of using quick variations in measured values for adjustment of the relation between the trailing force on the dredging arm and the pressure difference over the suction head and for attributing slow deviations to the changes in the water current.

The invention is further explained by way of the drawing, in which:

Fig. 1 shows a principle diagram of the operation of the Kalman filter; and
Fig. 2 schematically shows a floating dredge in which the various loads acting on the ship and the applied parts for controlling the ship have been indicated.

In the diagram of fig. 1:

X = X-coordinate of the ship in longitudinal direction;
Y = Y-coordinate of the ship in transverse direction;
PSI = course of the ship
in which index K: the X, Y, PSI estimated by the Kalman filter;
in which index m: the X, Y, measured by e.g. a DGPS and PSI measured with a compass;
rudder = angular rudder positions;
thruster = force of bow (and stern) screws;
props = force of propellers;
Fps = force in port suction tube;
Fsb = force in starboard suction tube;
Pps = differential pressure over port suction head;
Psb = differential pressure over starboard suction head;
Kps = estimated relation between Pps and Fps, so that estimated $\bar{F}ps = Kps*Pps$;
Ksb = estimated relation between Psb and Fsb, so that estimated $\bar{F}sb = Ksb*Psb$.

The difference vector $e^t = (Xm-XK, Ym-YK, PSIm-PSIK)$ between estimated and actual values is used for estimating the current and the relations Kps and Ksb:

Suppose	Ex = Xm-XK	longitudinal position error
	Ey = Ym-YK	transversal position error
	Epsi = PSIm - PSIK	course error
then	$e^t = (Ex, Ey, Epsi)$	

The estimated current vector $v^t = (Vx, Vy)$ is obtained by integration of Ex, Ey, e.g. in the most elementary form:

$$v = \int (A.e.).dt$$

$$\text{in which e.g. } A = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \end{bmatrix}$$

in which Vx = current in longitudinal and Vy in transverse direction.

The relations Kps are obtained by integration of the product of E and the pressure difference Pps over the suction head, e.g. in the most elementary form:

$$Kps = \int (Pps^t.(B.e)).dt$$

$$\text{in which e.g. } B = \begin{bmatrix} b_{11} & 0 & b_{13} \\ 0 & b_{22} & b_{23} \end{bmatrix}$$

and $Pps^t = (Pv_x, Pv_y)$ suction force (in the direction of the suction tube) resolved in longitudinal direction (= Pv_x) and transverse direction (= Pv_y) of the ship.

The same algorithm for the starboard suction tube:

$$Ksb = \int (Pps^t.(B.e)).dt$$

If no dredging takes place, the trailing force is basically zero. Owing to the rate of flow of the water to the dredge pump, yet a small pressure difference may arise over the suction head, as a consequence of which erroneous corrections might take place. This can be prevented by switching off the adaptation algorithm when the suction head is not situated on the ground. This can be derived from several dredging signals, e.g. from the force in the hoisting cables or signals derived from them, from the position of the swell compensator or from the measured concentration.

Claims

1. Method of measuring the trailing force exerted on a dredging arm during operation of a floating dredge, characterized in that said trailing force is derived from an algorithm using process data being measured during dredging.

2. Method according to claim 1, characterized in that the following data can be applied as process data, either individually or in combination:

   a) the concentration of the mixture brought up by dredging, in the suction tube;
   b) the velocity of the dredged mixture in the suction tube; and
   c) the pressure difference over the suction head.

3. Method according to claim 1 or 2, characterized in that with the use of a Kalman filter the relation between the actual trailing force exerted on the dredging arm and the measured pressure difference over the suction head is estimated continuously so that the actual trailing force can be calculated.

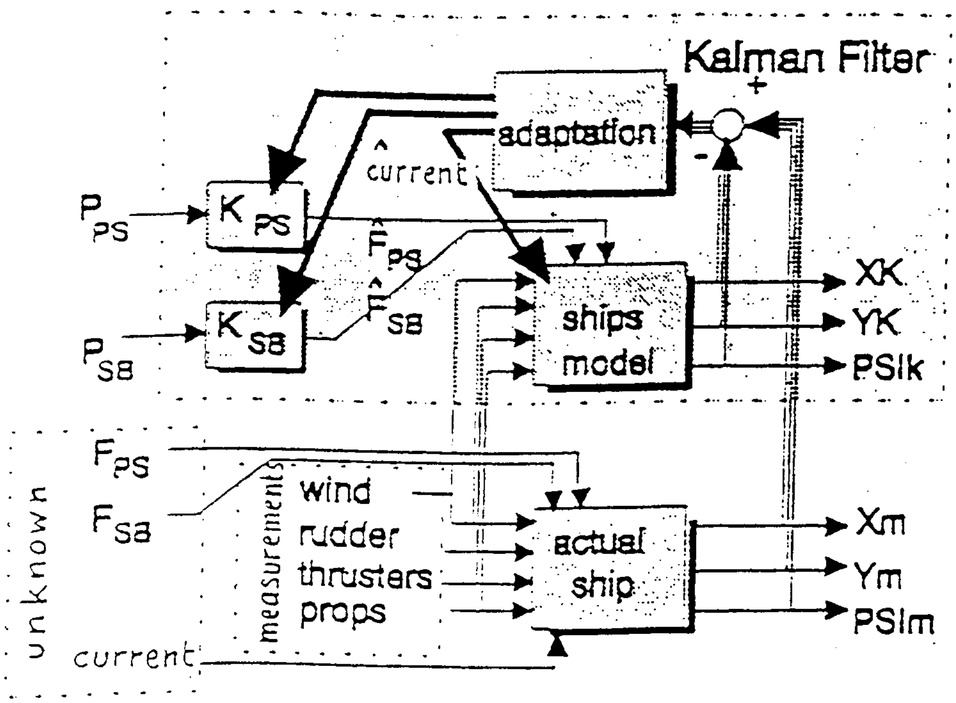
Kalman Filter
adaptation
current
P_{PS}
K_{PS}
$\hat{F}_{PS}$
$\hat{F}_{SB}$
P_{SB}
K_{SB}
ships model
XK
YK
PSIk
F_{PS}
F_{SB}
unknown
current
measurements
wind
rudder
thrusters
props
actual ship
Xm
Ym
PSIm

FIG. 1