Field Trials of ECPINS®[1] Vessel Positioning Algorithm

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Abstract - Since 1979, Offshore Systems Ltd. (OSL) has been involved in the development of Electronic Chart Display and Information Systems (ECDIS). OSL's ECDIS is called the Electronic Chart Precise Integrated Navigation System (ECPINS®). The accurate positioning of a vessel is a paramount requirement for an ECDIS. OSL's engineering department has expended considerable effort in the application of Kalman Filtering techniques for the integration of several marine navigation measurements which are used for estimating a vessel's position and kinematics.

Performance results, based on simulated measurement data, for preliminary versions of OSL's vessel positioning and radar tracking Kalman Filters were presented at the Jan '94 Institute of Navigation (ION) Technical Meeting. This paper gives an overview of OSL's Positioning Kalman Filter (PKF), and outlines the different modes of operation depending on which marine navigation measurements are available. Performance results, of the PKF, based on field trials using OSL's vessel, "the ***MV Surveyor***", navigating within Vancouver, B.C., Harbour, are also presented in this paper.

1.0 INTRODUCTION

An ECDIS system as part of an integrated bridge on a vessel has proven to be a very valuable navigation aid [1]. The unique characteristics of an ECDIS system is that it integrates radio navigation (e.g., GPS, DGPS, Loran C), gyrocompass, radar, and electronic navigational chart (ENC) information and displays the information in real-time on a video screen [2]. A mariner with an ECDIS navigation tool can navigate his vessel in extreme weather conditions day or night.

The ECDIS capability of displaying a vessel's position and velocity vector on an ENC in real-time demands that accurate algorithms for integrating the vessel's kinematic measurements are implemented.

The vessel positioning estimation filter is refered to as the Dead Reckoning Kalman Filter (DRKF). In marine navigation, dead reckoning is defined as obtaining position estimates by integrating estimates of the vessel's velocity vector ahead in time. Several navigational measurements are integrated in order to provide the mariner with real-time tracking of the vessel's position relative to coastal and bathymetric landforms and possible traffic. The measurements presently incorporated into the DRKF consist of GPS position and velocity, Loran C position, uniaxial and dual-axial speedlog velocity magnitude, and gyrocompass yaw readings.

This paper outlines OSL's DRKF which allows for the real-time estimation of the vessel kinematics. The kinematic and measurement data is designed to fit into a Kalman Filter (KF) formulation. The Kalman Filter is an optimal (in a least squares sense) recursive filter which is based on state-space, time-domain formulation of physical problems. Several of the marine navigational measurement aids are nonlinear in nature (e.g., gyrocompass and speedlog); therefore, it is necessary to apply a set of KF equations which takes into account these nonlinearities.

There are several creative KF variations for taking into account nonlinear dynamics, but the two most widely used are the Extended and Linearized Kalman Filter (EKF and LKF) and their derivatives. The LKF is designed so that it linearizes about some nominal conditions in state space, while the EKF linearizes about the state space that is continually updated with the state estimates resulting from measurements. The EKF is selected rather than the LKF because, in marine navigation, one is usually not linearizing about a nominal set of states.

OSL's DRKF is an eleven state Extended Kalman Filter. The states consist of the vessel's two dimensional position, velocity, and acceleration; two dimensional current velocity model; two dimensional Loran C error model; and a scalar speedlog error model. Section 2.0 of this paper outlines the DRKF implemented in OSL's **ECPINS®** and illustrates the different configurations of the DRKF operation, based upon the availability of the marine navigation measurements. Performance results, of the DRKF, based on field trials using OSL's vessel, "the ***MV Surveyor***" navigating within Vancouver, B.C., Harbour, are presented in Section 2.1.

2.0 DEAD RECKONING KALMAN FILTER

The formulation of the DRKF is outlined in reference [3]. The vessel positioning filter is summarized in this section for the purpose of continuity and to present modifications made for the dual axis speedlog, the case where the mariner is navigating with only a yaw reading from a gyrocompass, and pitch and roll corrections made for GPS and Loran C measurements.

The filter presented in reference [3] attempts to integrate all of the vessel's instrumention to obtain the most accurate vessel

[1] Electronic Chart Precise Integrated Navigation System

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position and velocity estimates. In addition, the DRKF takes into account vessel acceleration and ocean current velocity by modelling them as first order Gauss-Markov processes.

Gauss-Markov Process

To have more realistic vessel dynamics, the system model includes an acceleration state, a(t), which is modeled as a first order Gauss-Markov process driven by white noise. In addition, the ocean current, Loran C, and speedlog measurement errors are also modelled as Gauss-Markov processes [4].

A Gauss-Markov process is generated by passing white noise N(0,1)[2] through a linear system transfer function $(2\sigma^2\beta)/(s+\beta)$; thus, for the continuous system, one has

$$\begin{gathered}\dot{a}(t) = -\beta a(t) + \sqrt{2\sigma^2\beta}\,w(t),\ \textit{with} \\ E[w(t)w(\tau)] = \delta(t-\tau),\ T_c = \beta^{-1}\ \textit{is the} \\ \textit{time constant}\ (1/\text{sec})\ \textit{and}\ \sigma^2\ \textit{is the variance}\end{gathered} \tag{1}$$

To obtain the discrete form for equation (1), a sampling interval Δ was assumed and then (1) was solved over this interval. Since β is a constant, the state transition function is given by

$$\Phi = \Phi(k+1,k) = \exp^{-\beta\Delta} \tag{2a}$$

The input transition function can be determined by calculating the mean-square response of a(t),

$$\begin{aligned}\Gamma^2 &= 2\sigma^2\beta\int_0^\Delta\int_0^\Delta \exp^{-\beta u}\exp^{-\beta v}\delta(u-v)\,du\,dv \\ &= \sigma^2(1 - \exp^{-2\beta\Delta})\end{aligned} \tag{2b}$$

Thus the discrete model for the Gauss-Markov process can be written as

$$\begin{gathered}a(k+1) = a_w a(k) + b_w w_a(k) \\ \textit{where},\ a_w = \Phi,\ \ \textit{and}\ b_w = \Gamma\end{gathered} \tag{3}$$

In equation (3), $w_a(k)$ is a zero-mean, timewise-uncorrelated, unit-variance sequence with a Gaussian probability distribution function. The Gauss-Markov process, a(t), is therefore a zero-mean, exponentially-correlated random variable whose standard deviation is σ. The constant Φ can have a range of values from 0 to +1 for $\beta \geq 0$. For $\Phi \rightarrow 0$, a(t) changes rapidly and tends to be uncorrelated from sample to sample. For $\Phi \rightarrow 1$ the behaviour of a(t) becomes more sluggish and it tends to change little from sample to sample [5].

System Model

To specify the system equations in the standard KF form, the following states need to be defined

<u>*States to be estimated*</u>

$$\begin{aligned}
x_1 &\equiv \textit{vessel x position} \\
x_2 &\equiv \textit{current velocity in x direction} \\
x_3 &\equiv \textit{vessel velocity wrt ground in x direction} \\
x_4 &\equiv \textit{vessel acceleration in x direction} \\
x_5 &\equiv \textit{vessel y position} \\
x_6 &\equiv \textit{current velocity in y direction} \\
x_7 &\equiv \textit{vessel velocity wrt ground in y direction} \\
x_8 &\equiv \textit{vessel acceleration in y direction} \\
x_9 &\equiv \textit{Loran C error in x direction} \\
x_{10} &\equiv \textit{Loran C error in y direction} \\
x_{11} &\equiv \textit{speedlog error}
\end{aligned} \tag{4a}$$

The continuous system equation for the KF formulation is defined in the following standard form:

$$\dot{\underline{x}} = F\underline{x} + G\underline{w} \tag{4b}$$

Therefore, with the states as defined in equation (4a), the following state matrix, F, was derived together with the input matrix, G, for the continuous system model specified by equation (4b):

$$F = \begin{bmatrix}
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -\beta_c & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\beta_v & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -\beta_c & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_v & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_{lcx} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_{lcy} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_{sl}
\end{bmatrix} \tag{4c}$$

$$G = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\alpha_c & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_v & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \alpha_c & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \alpha_v & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_{lcx} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \alpha_{lcy} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \alpha_{sl}
\end{bmatrix} \tag{4d}$$

[2]The notation N(0,1) denotes a Gaussian random variable with mean 0 and variance 1.

where β_c, $\alpha_c = \sqrt{2\sigma_c^2\beta_c}$, β_v, $\alpha_v = \sqrt{2\sigma_v^2\beta_v}$, $\beta_{lcx,y}$, $\alpha_{lcx,y} = \sqrt{2\sigma_{lcx,y}^2\beta_{lcx,y}}$, β_{sl}, *and* $\alpha_{sl} = \sqrt{2\sigma_{sl}^2\beta_{sl}}$, *are defined by equation* (1) *for current, vessel, Loran C, and speedlog, respectively.*

The discrete transition matrix, Φ, of the state estimate extrapolation equation then becomes

$$\Phi = \begin{bmatrix} 1 & 0 & \Delta t & \Delta t^2/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_c & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_v & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & \Delta t & \Delta t^2/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_c & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \Delta t & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_v & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{lcx} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{lcy} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{sl} \end{bmatrix} \quad (5)$$

where a_c, a_v, a_{lc}, *and* a_{sl} *are defined by equation* (2) *for the current, vessel, Loran C, and speedlog state variables, respectively.*

The discrete covariance structure, Q_k, of the input sequence w(k) is calculated as follows:

$$Q_k = E\left[\underline{w}(k)\ \underline{w}(k)^T\right] \quad (6)$$

$$= E\left\{\left[\int_{t_k}^{t_{k+1}} \Phi(t_{k+1},u)G(u)\underline{w}(u)du\right]\left[\int_{t_k}^{t_{k+1}} \Phi(t_{k+1},v)G(v)\underline{w}(v)dv\right]^T\right\}$$

$$= \int_{t_k}^{t_{k+1}}\int_{t_k}^{t_{k+1}} \Phi(t_{k+1},u)G(u)E\left[\underline{w}(u)\underline{w}(v)^T\right]G^T(v)\Phi^T(t_{k+1},v)dudv$$

since $w(k)$ *is a white noise vector process, we have* $E\left[\underline{w}(u)\underline{w}(v)^T\right] = I_{7x7}\delta(u-v)$, *where* I_{7x7} *denotes a 7x7 identity matrix and* $\delta(u-v)$ *denotes the dirac delta function.*

Measurement System

The measurements presently incorporated into the dead reckoning filter consist of GPS position and velocity, Loran C position, dual axial and uniaxial speedlog velocity magnitude, and gyroscope vessel yaw.

The filter will dynamically configure itself based upon the availability of data from the above mentioned devices. Table I illustrates data from the different configurations of the DRKF based upon the availability of the measuring devices.

Table I lists four DRKF configurations based upon the availability of data from the vessel's sensors. The filter will operate in the DRKFA mode when DGPS positional and velocity information is available. Once DGPS data is lost the filter will switch to the DRKFB mode where GPS and Loran C positional data, and vessel velocity data (from speedlogs and/or gyrocompass vessel yaw) is processed within the filter. If both DGPS and GPS or Loran C measurements are not available, the filter will operate in the DRKFC mode. Mode DRKFD is a dead reckoning mode. In this case, all positional information is lost, and only data related to the vessel's velocity vector is fed into the filter in order to obtain new estimates of the vessel's postion.

Table I. DRKF Configuration Based Upon Availability of Measuring Devices

MODE	SENSORS
DRKFA	DGPS Latitude, Longitude, Vx, and Vy
DRKFB	GPS Latitude and Longitude, Loran C Latitude and Longitude, Velocity data from Speedlog and/or Gyroscope Vessel Yaw
DRKFC	Loran C or GPS Latitude and Longitude, Velocity data from Speedlog and/or Gyroscope Vessel Yaw
DRKFD	Velocity data from Speedlog and/or Gyroscope Vessel Yaw

The above modes are based upon the statistical accuracies of the available measurements. DGPS data can be accurate to within 2.5m, whereas GPS and Loran C measurements errors can have standard deviations greater than 40m; therefore, any integration of GPS and Loran C data with DGPS measurements will cause a significant degradation in the filter estimates.

The measurement vector based upon all the available sensor data is defined as follows

Measurements

z_1 ≡ *DGPS or GPS x position*
z_2 ≡ *DGPS or GPS y positbn*
z_3 ≡ *GPS x velocity wrt ground*
z_4 ≡ *GPS y velocity wrt ground*
z_5 ≡ *Loran C x position*
z_6 ≡ *Loran C y position*
z_7 ≡ *Speedlog longitudinal velocity*
z_8 ≡ *Speedlog transverse velocity* (7a)

or

z_7 ≡ *Speedlog longitudinal velocity*
z_8 ≡ *Gyroscope vessel yaw*

or

z_7 ≡ *Last speed made good (SMG)*
z_8 ≡ *Gyroscope vessel yaw*

or

z_7 ≡ *Manually entered yaw reading*
z_8 ≡ *Manually entered SMG*

Elements z_7 and z_8 describe measurements related to the vessel's velocity vector. If the vessel has a dual axis speedlog (ie., measuring velocity from stern to bow (longitudinal) and port to startboard (transverse)) the velocity vector is completely defined. If there is only a uniaxial speedlog available, the velocity vector's heading (course made good (CMG)) is estimated from the vessel's yaw reading. The last two conditions are related to the situation when the vessel does not have a speedlog and the last accurate vessel speed made good measurement (SMG) is used (eg., from DGPS), and the case when speedlog velocity and gyrocompass yaw readings are not available and these measurements are manually entered by the mariner.

The linearized measurement matrix, H, is given by the following equations

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & H_{72} & H_{73} & 0 & 0 & H_{76} & H_{77} & 0 & 0 & 0 & H_{711} \\ 0 & H_{82} & H_{83} & 0 & 0 & H_{86} & H_{87} & 0 & 0 & 0 & H_{811} \end{bmatrix} \quad (7b)$$

The elements H_{72}, H_{73}, H_{76}, H_{77}, H_{711}, H_{82}, H_{83}, H_{86}, H_{87}, and H_{811} describe the velocity vector measurements which require special consideration.

Velocity Measurements

As was previously stated, there are four possible vessel velocity data formats (ie., dual axial speedlog, uniaxial speedlog, manually entered SMG, and manually entered CMG and SMG).

The speedlog has two modes of operation, namely, "ground-lock" and "water-lock". Ground-lock occurs when the velocity measurements are made with respect to the sea floor. Water-lock occurs when the velocity measurements are made with respect to some depth within the sea water.

A vessel with a dual axial speedlog obtains readings along the axis of the vessel (longitudinal) and perpendicular to the axis of the vessel (tranverse). For this case, one has the following measurement model:

Ground-lock:

$$z_7 = x_3\sin(\psi) + x_7\cos(\psi) + x_{11} + v_7$$
$$H_7 = [0\ 0\ \sin(\psi)\ 0\ 0\ 0\ \cos(\psi)\ 0\ 0\ 0\ 1]$$

$$z_8 = x_3\cos(\psi) - x_7\sin(\psi) + x_{11} + v_8$$
$$H_8 = [0\ 0\ \cos(\psi)\ 0\ 0\ 0\ -\sin(\psi)\ 0\ 0\ 0\ 1]$$

where $\psi \equiv$ *vessel yaw angle*

Water-lock:

$$z_7 = x_3\sin(\psi) + x_7\cos(\psi) - (x_2\sin(\psi) + x_6\cos(\psi)) + x_{11} + v_7$$
$$H_7 = [0\ -\sin(\psi)\ \sin(\psi)\ 0\ 0\ -\cos(\psi)\ \cos(\psi)\ 0\ 0\ 0\ 1]$$

$$z_8 = x_3\cos(\psi) - x_7\sin(\psi) - (x_2\cos(\psi) - x_6\sin(\psi)) + x_{11} + v_8$$
$$H_8 = [0\ -\cos(\psi)\ \cos(\psi)\ 0\ 0\ -\sin(\psi)\ \sin(\psi)\ 0\ 0\ 0\ 1]$$

where $\psi \equiv$ *vessel yaw angle*

For a vessel with a uniaxial speedlog (longitudinal) and gyrocompass yaw reading (provides estimate of the vessel's CMG), one has the following measurement model:

Ground-lock:

$$z_7 = x_3\sin(\psi) + x_7\cos(\psi) + x_{11} + v_7$$
$$H_7 = [0\ 0\ \sin(\psi)\ 0\ 0\ 0\ \cos(\psi)\ 0\ 0\ 0\ 1]$$

$$z_8 = \arctan((x_3 - x_2)/(x_7 - x_6)) + v_8$$
$$H_8 = [0\ H_{82}\ H_{83}\ 0\ 0\ H_{86}\ H_{87}\ 0\ 0\ 0\ 0]$$

where $H_{82} = -(x_7 - x_6)/A$, $H_{83} = (x_7 - x_6)/A$,
$H_{86} = (x_3 - x_2)/A$, $H_{87} = -(x_3 - x_2)/A$,
and $A = (x_3 - x_2)^2 + (x_7 - x_6)^2$

Water-lock:

$$z_7 = x_3\sin(\psi) + x_7\cos(\psi) - (x_2\sin(\psi) + x_6\cos(\psi)) + x_{11} + v_7$$
$$H_7 = [0\ -\sin(\psi)\ \sin(\psi)\ 0\ 0\ -\cos(\psi)\ \cos(\psi)\ 0\ 0\ 0\ 1]$$

z_8 = *as defined above*
H_8 = *as defined above*

where $\psi \equiv$ *vessel yaw angle*

The last two cases of velocity vector data input have measurement model equations identical to that of the unaxial speedlog and gyrocompass readings. In these cases, the measurement errors, v_7 and v_8, are increased to reflect the loss of velocity data.

Positional Data Corrections for Pitch and Roll

When using the DGPS, GPS, and Loran C positional data as input into the DRKF, it is necessary to correct these measurements for pitch and roll of the vessel. These corrections are defines as

$$dx_{rp} = dx\cos(\phi) - dy\sin(\theta)\sin(\phi) + dz\cos(\theta)\sin(\phi) \quad (8a)$$
$$dy_{rp} = dy\cos(\theta) - dz\sin(\theta) \quad (8b)$$
$$dz_{rp} = dx\sin(\phi) - dy\sin(\theta)\cos(\phi) + dz\cos(\theta)\cos(\phi) \quad (8c)$$

where
dx, dy, and dz are the instrument offsets from the vessel origin
dx_{rp}, dy_{rp}, *and* dz_{rp} *are the instrument offsets from the vessel origin corrected for pitch and roll*
$\phi \equiv$ *vessel roll angle*
$\theta \equiv$ *vessel pitch angle*

As was previously mentioned, the measurement matrix requires that its dimensions be adjusted dynamically depending upon current available measurements. For instance, if the filter is in mode DRKFA, one has a linearized measurement matrix of dimensions 4x11. In mode DRKFB, the measurement matrix has dimensions of 6x11. The measurement matrix dimensions for mode DRKFC is 4x11 and that for the DRKFD mode is 2x11.

Estimation of Error Parameters

The Loran C and current Markov error parameters are determined when DGPS, Loran C, and Water-Lock Speedlog data are available. The filter takes the difference between these measurements in order to obtain the Loran C error and current velocity model constants. A moving average of the variance and autocorrelation are calculated in order to derive the necessary error parameters of the time constant and the variance.

The computational sequence for the dead reckoning KF is summarized as follows:

- ***At t_o specify $\underline{\hat{x}}_o$ and P_o, and compute Q_o, $\Phi(1,0)$, h_1, $H_1 = \frac{\partial h_1}{\partial \underline{x}}$ and R_1.***
- ***At t_1 compute the projected estimate of the covariance matrix $P(1|0) = \Phi(1,0)P_o\Phi(1,0)^T + Q_o$.***
- ***Compute the gain matrix $K_1 = P(1|0)H_1^T(\Phi(1|0)\underline{\hat{x}}_o)\left[H_1(\Phi(1|0)\underline{\hat{x}}_o)P(1|0)H_1^T(\Phi(1|0)\underline{\hat{x}}_o) + R_1\right]^{-1}$.***
- ***Using the measurement $\underline{z}_1$ at $t=t_1$, the best estimate of the state at t_1 is given by $\underline{\hat{x}}_1 = \Phi(1|0)\underline{\hat{x}}_o + K_1\left[\underline{z}_1 - h_1(\Phi(1|0)\underline{\hat{x}}_o)\right]$.***
- ***The estimation covariance matrix at t_1, is given by $P(1|1) = P(1|0) - K_1H_1(\Phi(1|0)\underline{\hat{x}}_o)P(1|0)$.***
- ***At $t=t_2$, a new measurement $\underline{z}_2$ is obtained and the computational cycle is repeated.***

2.1 FIELD TRIALS OF DRKF

Performance results of the DRKF based on field trials using OSL's vessel, "the ***MV Surveyor***", navigating within Vancouver, B.C., Harbour, are presented in this section.

State estimates for the DRKFB, DRKFC, and DRKFD modes of operation of the filter are outlined and analyzed. The effect of the loss and gain of measurements was achieved by navigating through radio signal disruptions (eg., under bridges) and disabling input into the filter through the software user-interface and then comparing the filter's performance with accurate DGPS measurements.

MV Surveyor

"The ***MV Surveyor***" is a 54 ft steel hull research vessel which has been in operation since 1972. OSL software, developed in-house and tested with simulators, is loaded onto the ECPINS navigating system on the research vessel and put through field trials.

The navigation sensors currently installed on "the ***MV Surveyor***" included a Northstar Navigator Loran C receiver which sends data at a rate of 0.5 Hz, Magnavox 4200D GPS and Magnavox MX-50R differential receivers which update at 1 Hz, Yokogawa Navitec Gyrocompass which operates at 10 Hz, and a B&G Network inpeller type uniaxial speedlog which sends data at 1 Hz.

Results

DRKFB - Figure 1 illustrates a comparison of the vessel track histories between GPS postioning and the filter estimates. The Magnavox receiver switches to GPS positioning due to radio signal disruptions when going under the bridge. In this mode of operation, the filter makes use of the GPS and Loran C positioning data, uniaxial speedlog along the longitudinal axis of the vessel, and the gyrocompass yaw readings.

Figure 1 illustrates that the filter positioning did not jump with the loss of the DGPS corrections, and the DRKF did not veer off the true course. With the return of the DGPS corrections, the filter weighs the DGPS measurements highly and essentially jumps to these positional measurements. As is illustrated in Figure 1, there is no jump in the filter estimates when the DGPS measurements returned; therefore, the DRKFB mode gave fairly accurate positioning estimates during the loss of the DGPS radio signal.

DRKFC - Figure 2 illustrates two vessel track histories between Loran C positioning measurements and the filter estimates. The loss of the DGPS and GPS positioning and velocity measurements was simulated by disabling the data as input to the filter through the software user-interface. In this mode of operation, the filter makes use of the Loran C positioning data, uniaxial speedlog along the longitudinal axis of the vessel, and the gyrocompass yaw readings.

Figure 2 shows that the filter positioning did not jump with the loss of the DGPS and GPS measurements. This point is further illustrated by considering that the Loran C position measurements are nearly 0.08 nm in error from the true position. The loss of the accurate DGPS positional and velocity measurements results in the error in the filter estimates growing with time. This is shown by the error ellipse around the filter positional estimate. The growth of the error ellipse is bounded by the Loran C measurement errors.

Figure 3 illustrates the vessel track history between the DGPS measurements and the filter estimates in the DRKFC mode. As shown, the filter slowly starts to veer off the true vessel course which is indicated by the error ellipse. At the location indicated, the DGPS measurements are again fed into the filter and there is the expected filter jump to the positional measurements of the DGPS receiver.

It should be noted that the SMG measurements of the DGPS and speedlog differ by 1.3 knots due to the speedlog's relatively poor accuracy.

DRKFD - Figure 4 illustrates two vessel track histories between DGPS positioning measurements and the filter estimates. In this mode of operation, the filter makes use of the uniaxial speedlog along the longitudinal axis of the vessel and the gyrocompass yaw readings.

The loss of the accurate DGPS position and velocity measurements and Loran C measurements results in the error in the filter estimates to grow with time. This is shown by the error ellipse around the filter's positional estimates. The growth of the error ellipse is not bounded in this case and grows relative to the speedlog error and current velocity models. The DGPS measurements are within the error ellipse around the filter estimates which is desired for 95% confidence in estimates.

Figure 5 illustrates another example (Test B) of the DRKFD mode of operation. Test B has the same conditions as the previous test case but, in this run, the vessel makes slightly more complicated maneuvers.

3.0 CONCLUSIONS

Performance results of OSL's Dead Reckoning Kalman Filter have been presented. The DRKF was found to perform well for different measurement configurations while undergoing field trials using OSL's vessel, "the ***MV Surveyor***" navigating in Vancouver, BC, Harbour.

Currently, work is progressing into the application of statistical tools for the identification of soft-failures and hard-failures of marine measuring devices.

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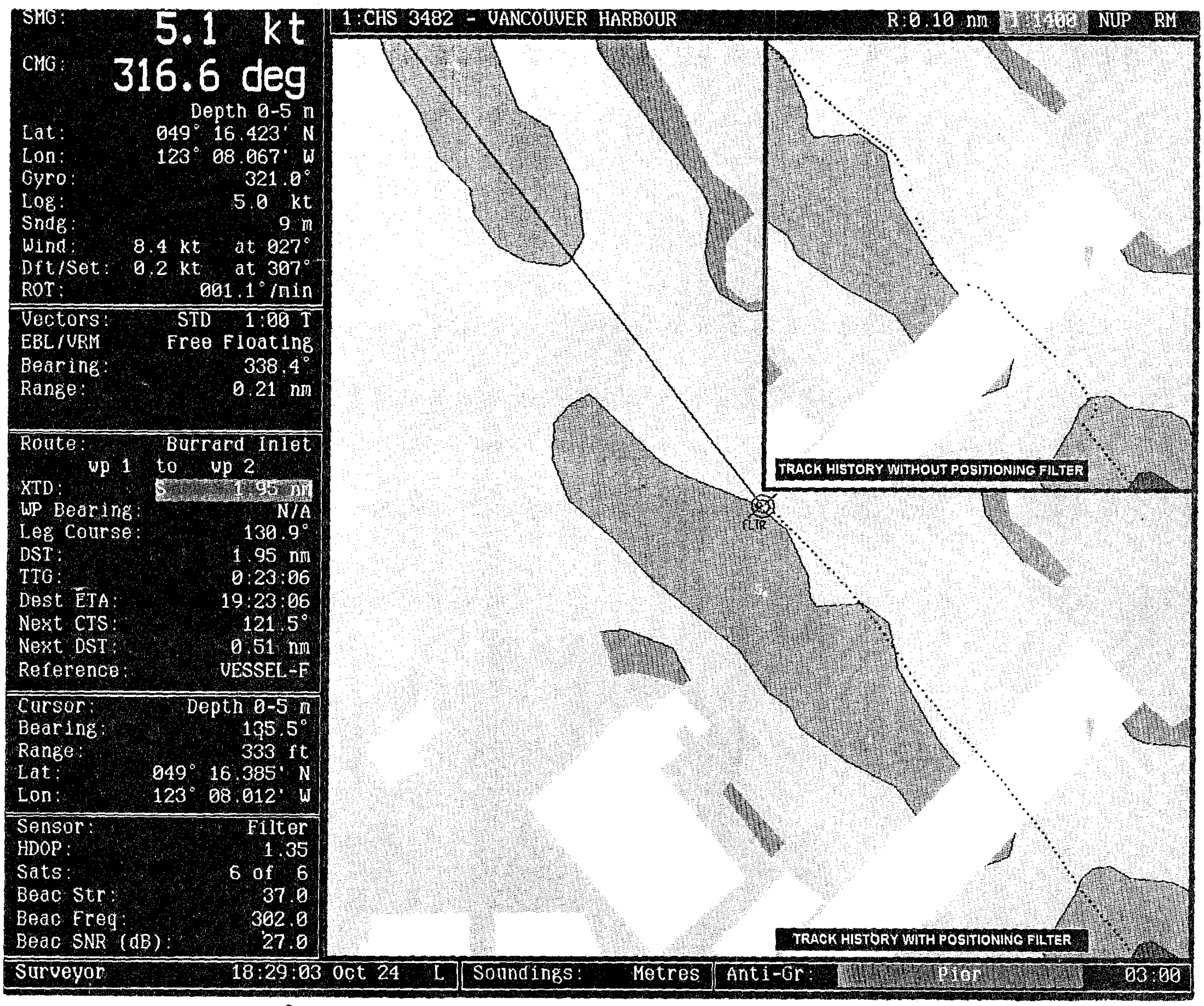

Note: The DRKF in **ECPINS®** uses all available navigation sensors to prevent position jumps caused by DGPS satellite signal interruptions under a bridge.

Figure 1. Evaluating Filter in <u>DRKFB</u> Mode of Operation.

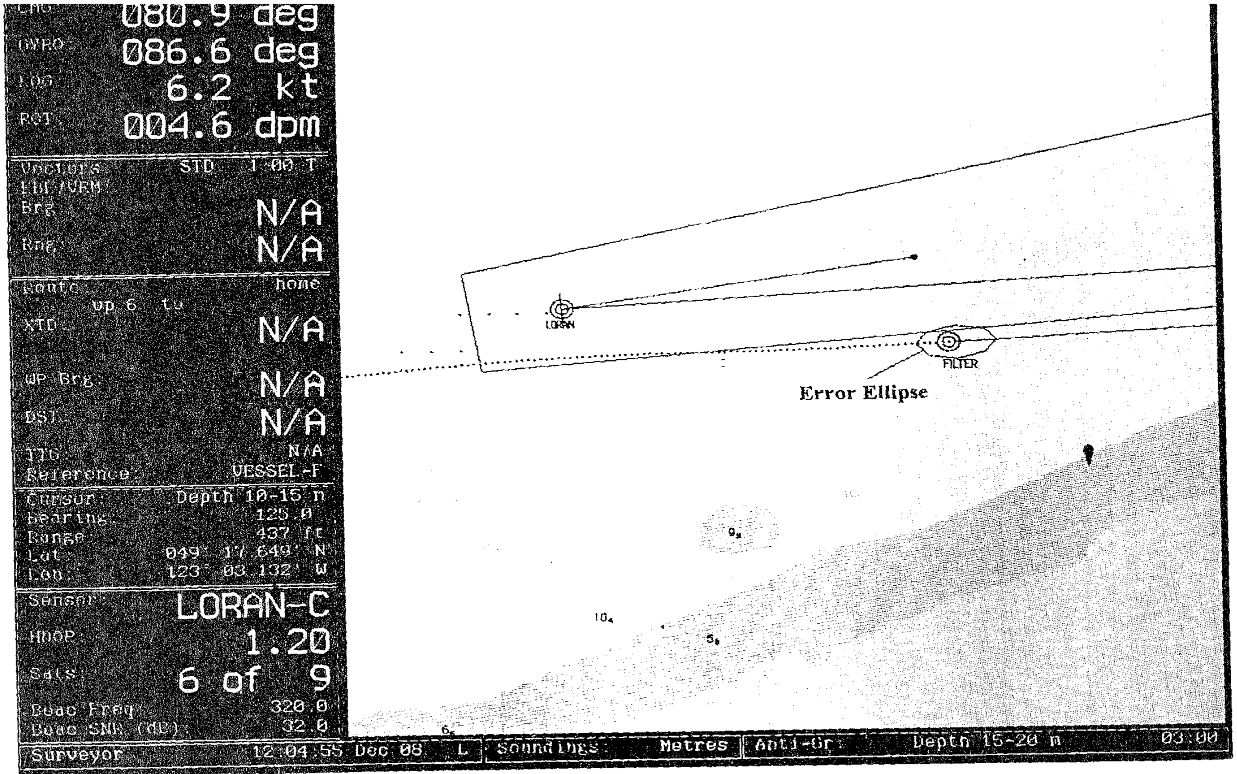

Figure 2. Illustrating Loran C and Filter Position Estimates in DRKFC Mode of Operation .

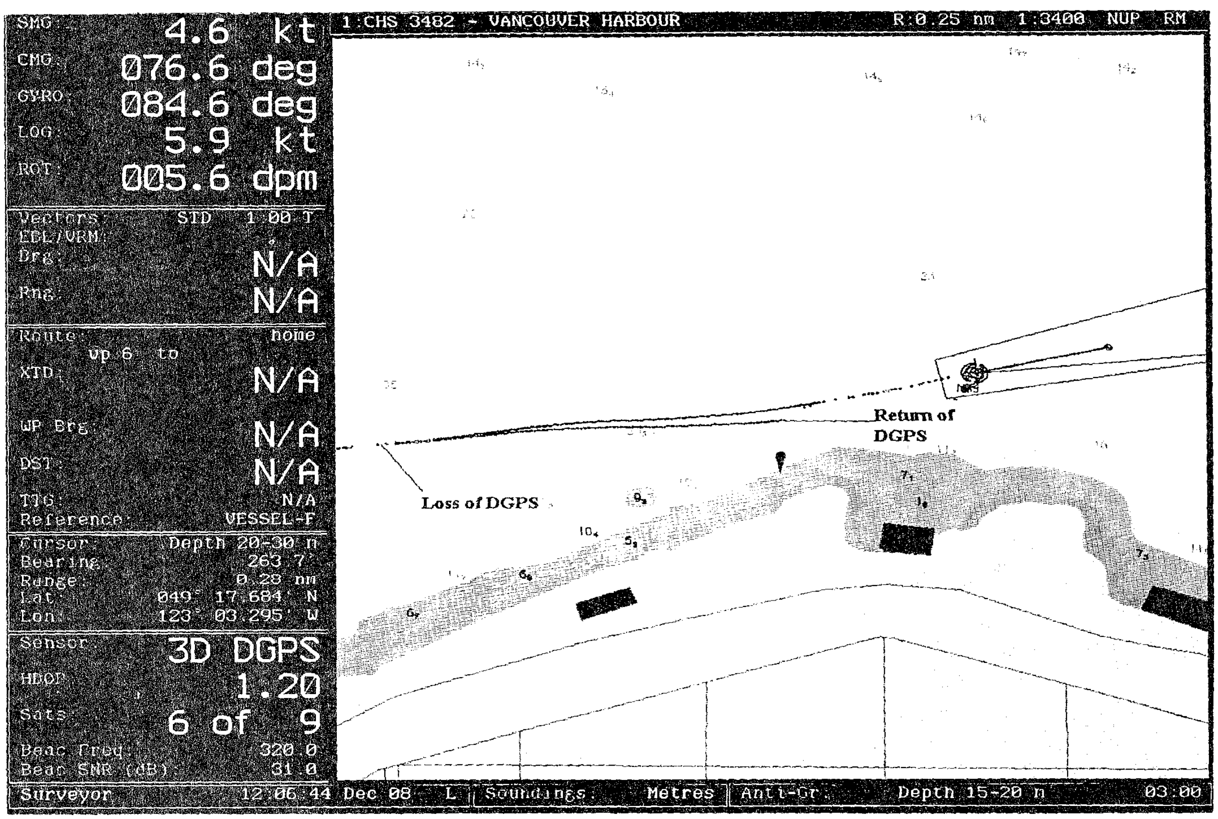

Figure 3. Return of DGPS Measurements to Filter in DRKFC Mode of Operation .

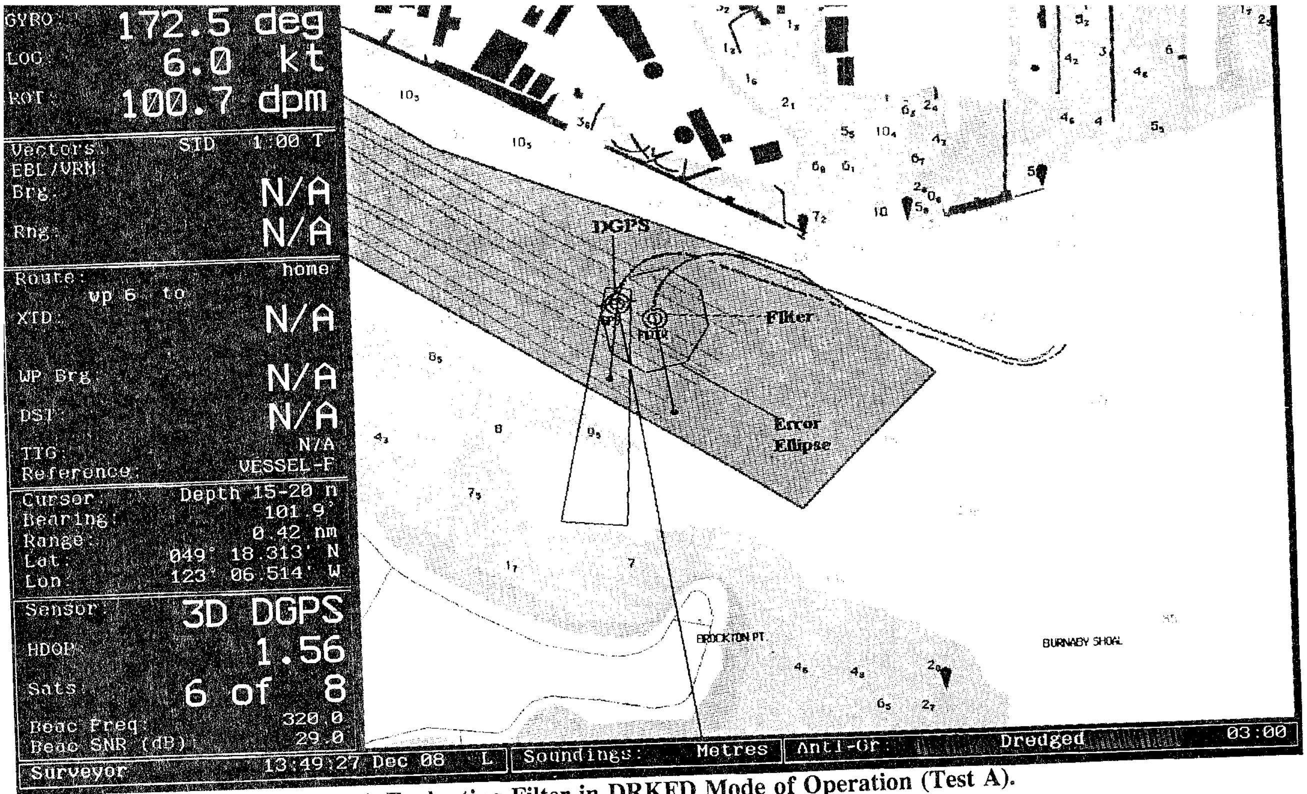

Figure 4. Evaluating Filter in DRKFD Mode of Operation (Test A).

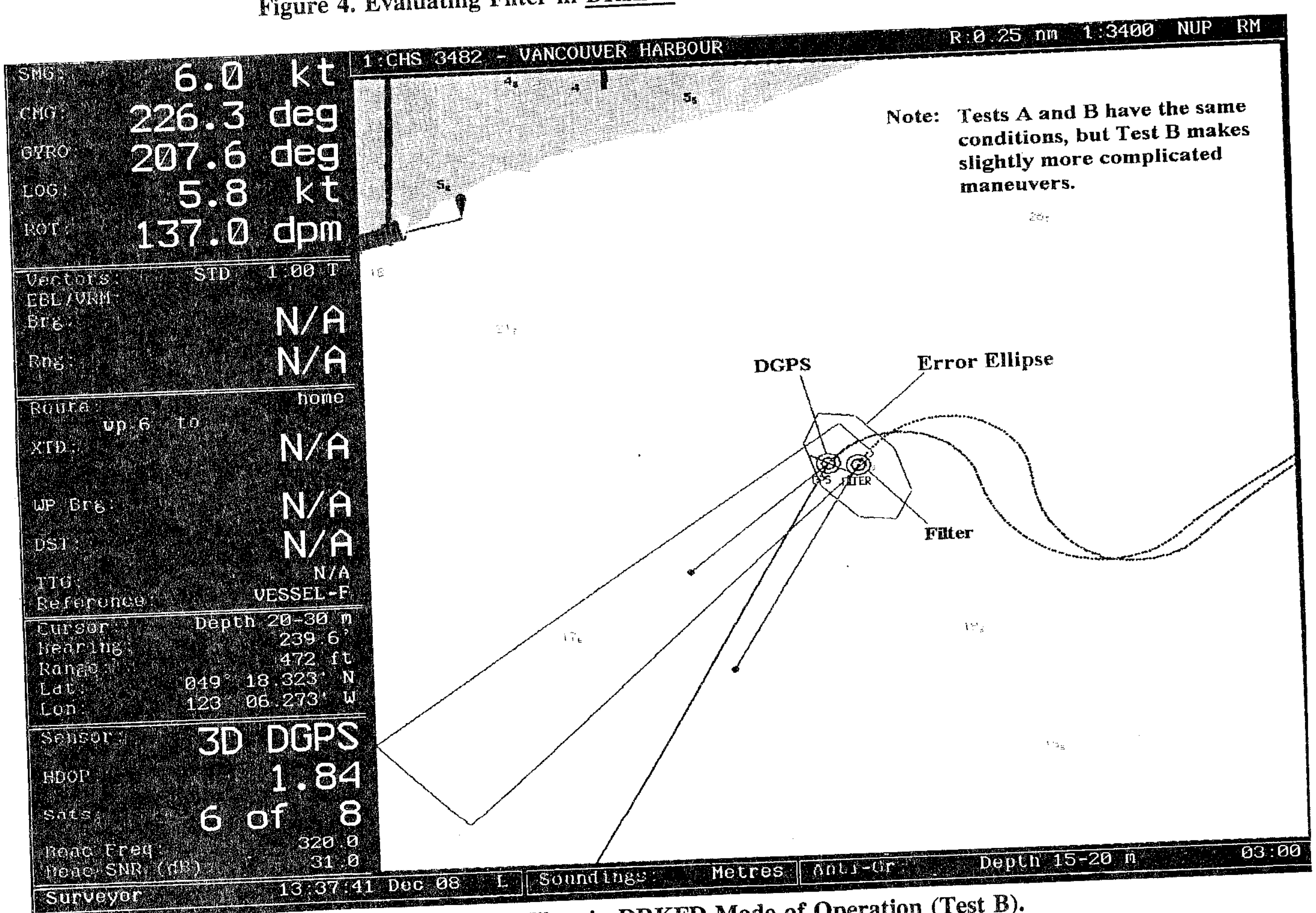

Figure 5. Evaluating Filter in DRKFD Mode of Operation (Test B).