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DYNAMIC POSITIONING CONFERENCE

October 12-13, 1999

SENSOR SESSION

Quality Measures Applied to the Management of Offshore Navigation and Positioning Data

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DP operations are becoming increasingly complex to manage. Multiple vessel operations are being used in major deep-water projects, where small delays can lead to significant cost overruns. Redundant positioning systems (multiple surface and subsurface measurement and positioning devices) operating simultaneously are now the norm. Often these systems are used to the limits of manufacturers' recommended capabilities in a variety of environmental conditions (extreme depths, currents and ambient noise). Such systems may reduce vessel requirements at the expense of operational complexity (e.g. running USBL at 3000 feet from a J lay vessel to avoid use of a survey boat). These situations can lead to serious difficulty and uncertainty for navigation system operators in the field implementation phase of a project.

Quality assurance in data management is vital to determining that correct and useful observations and positions are acquired during offshore Dynamic Positioning activities. The volume of data acquired, coupled with the speed of response, makes it impossible to perform quality management manually. Therefore a series of statistical measures and tests are applied within software applications to assist this process. In a well-managed operation, these tests will help avoid crises and determine acceptance and rejection criteria in accordance with contract specifications. Such tests will smooth field operations and significantly improve the financial performance of the project.

Regardless of whether data is derived from satellite systems (DGPS), terrestrial systems or peripheral devices (acoustics, laser, compasses etc.) the same principles of quality management apply. This will permit direct, real-time comparison between the performance of different positioning systems in various modes of operation.

In a DP application it is essential that quality measures be integrated into real time navigation systems to assist stable and reliable station keeping. Poor data will introduce position busts and data jumps that must be avoided. The aims are to eliminate risk of collision (between vessels), damage to heavy equipment personnel and ROVs and unnecessary bow thruster activity. This paper recommends a suite of industry standard data management tools that aid understanding of the validity of real-time operational positioning systems.

Introduction

Data management and data quality control are intrinsically related. In order to manage data volumes, an assessment of the data quality must be made. When properly implemented observation and positioning quality allow unreliable navigation data to be eliminated. Without this it is not possible to determine the usefulness of the data. In many DP operations, such ignorance could permit poor positioning to go unnoticed. In cases where relative station keeping (in one single location) is paramount, serious unintended movement will not escape detection. However, such errors may have a dramatic effect on the ability of the vessel to maintain a required station. This could endanger vessels and personnel and cause serious delays in production.

Two 'types' of positioning are used in DP operations. The first are 'absolute' earth relative co-ordinate systems, primarily derived from DGPS and GLONASS. The second is relative or 'local' positioning. This is where acoustic, laser and gyro data are used to maintain a track in relation to a pre-plot line or where a vessel attempts to maintain a fixed location. DGPS is used to provide surface position of vessels. It is also used to establish and calibrate the relative positioning networks. Both relative and absolute systems are operated in redundant mode (i.e. two or more systems are used and compared). Both types of positioning are prone to noisy environments, poor data quality, and in some cases are operated outside design parameters (either by mistake or necessity).

Differential GPS (DGPS) is now the fundamental real time 'absolute' surface positioning system for DP. It is common that two or more systems will be deployed on the same spread. This permits cross checking and investigate disparities between systems. This helps to ensure that errors within a system are eliminated prior to use (and in a manner that precludes manual intervention). Many of the QA/QC processes highlighted in this paper are often attributed to DGPS. However, they all pre-date DGPS and have traditionally been used on terrestrial and subsurface survey observations including gyro compass headings, laser measurements and acoustic systems.

The fundamental aim of data management is to ensure observations are free from blunders. Thus, positions will be stable and free from data jumps. Because data volumes are becoming larger (particularly with multiple systems) it is impossible to perform data management manually. Therefore, to automate the process a set of statistical tests needs to be integrated into firmware and software to eliminate biased observations prior to computing positions and performing station keeping. The automation of this process has two principle advantages. Firstly, the data volume will be subjected to the same tests and secondly, the requirement for manual intervention is reduced or obviated altogether.

Observation blunders may be eliminated using statistical testing; and positioning integrity is described using precision and reliability quality measures. All the indicators described within the paper are those recommended for use by UKOOA Survey and Positioning Committee and adopted by the International Marine Contractors Association (IMCA).

What follows is classification of errors followed by an introduction to the statistical tests and quality measures.

Observation Error Classification

No survey observation is entirely free from error because all stages of the observation process are subject to variation, whether it is introduced from atmospheric conditions, RF noise, temperature, salinity etc. As all observations are subject to variation it follows that no quantity is completely determinable. We may seek the truth but what we get is no more than an estimate of the true value. The difference between the quantity measured and the true value is known as error. Thus, the term error as it is used in this paper means inexact to some specified degree, as opposed to wrong. The study of errors is as important as studying the observations themselves. Errors have traditionally been classified into three categories, namely: Random, Systematic and Blunders (Gross Errors).

Random Errors

Random errors relate to fluctuations in the propagation medium and most cannot be adequately predicted. Therefore, they cannot be removed from the observations and they remain with unpredictable magnitude. However their behaviour can be studied using probability theory.

Systematic Errors

Systematic errors occur according to some pattern, which if known, can be described mathematically. They are called constant errors if their magnitude and sign remain the same throughout all the observations. The error may be introduced by the instrument, the observer, physical or environmental conditions. An example would be an observer entering an incorrect parameter into the operating software. Regardless of where the error has been introduced it is vital that this type of error be identified and eliminated if the final survey results are to serve any usefulness.

Blunders

Blunders or mistakes are sometimes referred to as Outliers or Gross errors. The latter term is confusing because as described above, error is something referring to measurable in-exactitude. If the errors are of large dimensions they are usually easy to identify and the observation simply removed. However, not all blunders are large. Sometimes they are numerically small and go unnoticed. Therefore blunders must be identified and removed from the data set if the final positions are to have any meaning.

How are errors described statistically?

During positioning and navigation computations, there are a number of questions regarding the significance of not only the observations, but also the computed parameters. Case one is where we want to know if all the observations come from the same population (i.e. no blunders). Case two is where two measurements of the same quantity significantly differ. Statistical testing provides a means of answering these questions.

It is usual to describe errors (not the observations) with respect to some probability distribution. This describes the probability of an event (e.g. error of a certain size) occurring with respect to a certain distribution. For observations the Normal Distribution (Fig 1) is the most commonly used.

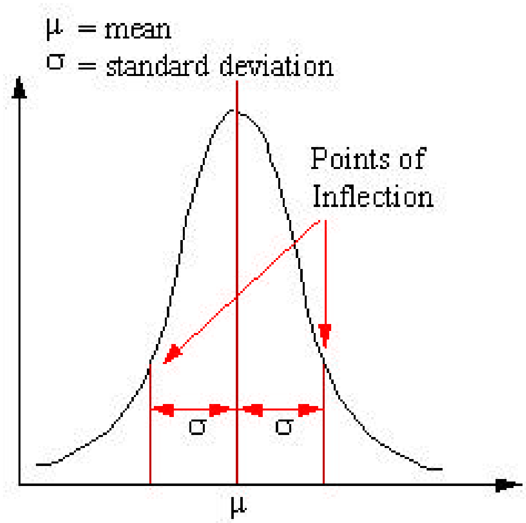

Fig 1 Normal Distribution

The probability of an event occurring, close to the mean, is high and the probability of an event occurring away from the mean are low. In this model it is assumed that the mean error will be zero and the probability of errors being very small (within good observations) will be high. The probability of large errors occurring will be lower. With the Standardised Normal Distribution there is a 68.26% probability that an event (error) will occur within 1 standard deviation of the mean, a 95% probability they will occur within 1.96 standard deviations of the mean and 99% probability they will occur within 2.57 standard deviations of the mean.

Eliminating observation Outliers

The identification of observation Outliers is called data snooping or outlier detection and has been widely used with both terrestrial and DGPS survey observations. When a position is computed, each observation used in the position fix will be assigned a residual (e.g. Least Squares Adjustment). The residual is the amount by which each observation is adjusted in order to make them fit. Observations that contain large errors will invariably have large residuals and vice versa.

Prior to using the observation in the position fix it is assigned a standard deviation that is an estimate of how much error is considered to be within the observation. If a high quality system is used it will be assigned a low standard deviation.

A test statistic is computed using the residual and the observation standard deviation. This computed statistical value is tested against a level of acceptance to automatically determine if the observation contains an error. This test is referred to as the W-test.

Position Quality Measures

There are two common components that are used to describe the quality of a position fix: precision and reliability.

Precision

Precision relates to the likely effect random observation errors have on the positions and/or quantities derived from them. Precision measures can either be global (describing the whole system) or local (describing just a small part of the system). Precision measures can also relate to either estimable or non-estimable quantities.

Consider a DGPS position fix. All the GPS observations used in the fix contain some random error, or noise. These errors comprise (amongst others) the unmodeled effects of the atmosphere, antenna and receiver electronics. These observations are used within a mathematical least squares estimation process to compute receiver position. The random errors in the observations will then affect the precision of this position. It is therefore meaningless to quote a position from a DGPS position fix without also stating the associated precision because the position will only be the best estimate and not the truth.

The most common types of precision measures are the Horizontal Error Ellipse, Standard Error, Circle Error Probability and d_{RMS}. Each will be briefly examined.

The Horizontal Error Ellipse (Fig 2) is used as a close graphical approximation of the true precision in all directions (the true shape is known as a pedal curve). If the ellipse is centered on the true position (which of course is unknown) then for a probability of n% there is a n% chance of the estimated position lying within the boundary of the ellipse.

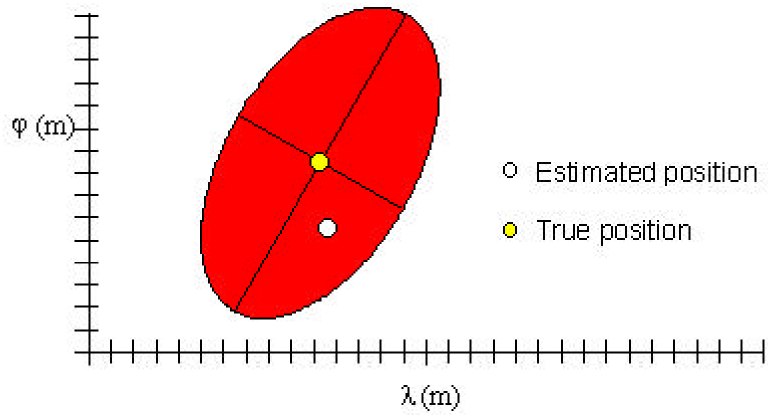

Fig 2 Horizontal Error Ellipse

Precision measures for the individual position components (often termed positional standard errors) describe similar information but are one-dimensional (e.g. latitude standard error or longitude standard error) whereas the error ellipse is two-dimensional (horizontal plane).

Associated with each of the precision measures is a probability measure. Thus the precision measures describe the probability of an error of a certain size (as defined by the precision measure) occurring. When precision measures are computed they have a natural probability level of 68.26% for the individual position components and 39.4% for the horizontal error ellipse (the difference being due to the dimensions). It is recommended that a confidence level of 95% is used when describing precision measures, and as such computed precision measures must be scaled (by a factor of 1.96 for individual precision and 2.447 for error ellipses).

There are two additional precision measures that are often used in conjunction with position fixes. The distance root mean square (d_{rms}) is defined as the root mean square of the distance between the true and estimated positions (either in two or three dimensions). The circular error probability (CEP) describes the radius of a circle inside which there is a **50% probability** of the position being located. A comparison of all the precision measures is given in Fig 3.

In deep-water applications, the vertical dimension becomes highly significant when relating surface to seabed measurements and positions (e.g. setting out and calibrating a LBL network). Thus it is necessary to examine position accuracy probability in 3 dimensions. In which case the equivalent probability level and scaling have to be applied.

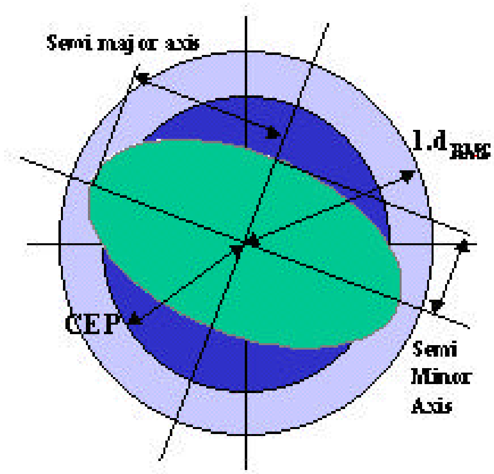

Fig 3 Comparison of Precision Measures

Reliability

Reliability is a measure of *checkability*. There are two basic forms of reliability:

- Internal reliability - The ability of a system to detect outliers and/or biases
- External reliability - The effect an undetected outlier and/or bias has on the system.

Internal Reliability

Internal reliability is used to describe the size of Blunders, or Outliers, that will be identified using a test statistic. High internal reliability means that small blunders can be identified and removed from the position fix. Low internal reliability means that blunders are likely to escape detection. Internal reliability is measured using the marginal detectable error (MDE).

The MDE describes the potential size of the error that can be detected given the geometry of the position fix and the redundancy. The MDE does not state that an error has occurred. It simply expresses the likelihood (in terms of probability) that if an error does occur it will only be detected by the statistical tests if it is of that size or greater (with a given probability). Internal reliability is intrinsically linked to the geometry of the observation scheme.

External Reliability

External reliability of a position fix describes the effect that an undetected outlier in an observation will have on the final coordinates. In other words, if an error of 12.453

meters occurred in the observation from satellite 12 and remained undetected what would happen to our position.

There will be one measure of external reliability for each observation on each position component. Therefore if we have six observations and three unknown position coordinates there will be 18 external reliability figures for that fix. Therefore it is only recommended that the largest effect of the individual MDEs on the horizontal positions be reported.

External reliability is perhaps more important than internal reliability. If an undetected outlier has no effect on the position parameters (i.e. the coordinates) then it is of little importance if it remains undetected.

Conclusions

DP is a real time operation that is highly dependent upon maintaining a stable reliable platform. A range of quality control tools exist, that when integrated in to real-time DP software, perform industry standard QA/QC on DGPS and other survey observations. As all navigation observations are subject to error it is imperative that the scale of the errors is measured and blunders be removed. In this way the accuracy and stability of observations will be maintained. Contracts must be prepared to provide this control. DPOs and surveyors must have suitable experience and be properly trained in order to interpret the quality position indicators.

This is vitally important for DP operations involving drill ships, pipe-laying/surveying and facility installation vessels, and FPSO fluid transfer operations. To ensure the navigation data used by the DP system is of sufficient quality, data management becomes an essential aspect of the procedure. Noisy observations and associated position jumps occur. These may be caused by poor system performance or bad design, uncontrollable environmental conditions such as sunspots/ionospheric disturbance or loop currents, poorly specified equipment and inexperienced operators. The use of the principles described in this paper, in the control systems hardware and software, will contribute significantly to the elimination of corrupt and noisy observations. In turn, this will lead to more efficient execution of projects, lower operational costs and greater financial success.

Biographies

Martin Rayson is a Geodesist with Quality Engineering and Survey Technology Ltd (Quest). He holds a B.Sc. in Applied Sciences, a M.Sc. in Geophysics and Planetary Physics and a Ph.D. in Surveying Sciences. He has been with Quest for the past 5 years, providing advanced geodetic and geophysical solutions to the hydrographic and land survey industries.

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