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UPOS, A HYDROACOUSTIC POSITIONING SYSTEM FOR HIGH PRECISION AND LARGE DYNAMICS

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ABSTRACT

This paper describes UPOS, a hydroacoustical system for three-dimensional, real-time position fixing of submerged objects. Originally it was designed for positioning and precise tracking of moving models in a research tank, the maximum range approaching 100 meters. Some of the most important design criteria were positioning of free running objects, sub-mm resolution, mm-range precision, high sampling rates (10 Hz), configuring flexibility, modular construction and to a maximum degree self calibrating.

To allow these rigid spesifications to be met, UPOS utilizes long proven, conventional techniques along with new technology. The hardware is built around a VME multiprocessor system although the concept is essentially independent of processor or bus structure. The complex handling of a maximum of 96 detections per sampling is secured by using modern FIFO components. PALs with up to 1800 gates are used where ever the constrainment of circuit complexity and space limitations dictate it.

The unique modular construction and design simplicity of UPOS invites to any configuration of number of hydrophones and frequency or time multiplexing within the frequency range of several octaves. A majority of these features are software controlled.

The mathematical processing of acoustical data is comprised by three main parts; calibration of the system, synchronizing the system timebase and real time positioning.

The UPOS system has greatly benefitted from the participating engineers and researchers' experience with satellite navigation software, real-time processing and hydroacoustical systems.

INTRODUCTION

In the spring of 1986, IKU, Department of Exploration Technology, was asked by MARINTEK, a second SINTEF institute, to undertake a very significant part of a new instrumentation project at their ocean laboratory site in Trondheim. The intentions of the project may be summerized as that of providing an integrated tool for testing submerged models in the Ocean Laboratory basin offering much the same properties as the then already existing fascilities for surface models. Main objectives had already been pointed out to be positioning of models and communication between model and data acquisition equipment.

The various backgrounds at IKU that facilitated participation in the project were various work within hydroacoustics, sub-sea position fixing and electro-magnetic propagation. At a later stage, recent experience with the development of the Navstar [1] based DIFFSTAR [1] navigation system contributed largely to a healthy course of the project.

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The story about UPOS begins back in 1981 when a hydroacoustic positioning system for MARINTEK was developed over a very short period of time in order to carry out a model experiment involving some slowly moving offshore structures. This system employed no processor system, had a very simple interface to the host computer and provided no software controlled parameters. However, practical experience with this system showed good resolution and accuracy in the sub-cm range. A hydroacoustical positioning system had therefore to be strongly considered when feasibility studies incorporating the various instrumentation requirements were carried out during spring and summer of 1986 [2].

The concepts for a positioning system reviewed were different configurations of hydroacoustic equipment, but also the use of radio frequencies (VHF) and the use of laser technology was covered. Briefly summarized, specifications were; accuracy to a few mm, six degrees of freedom, ability to upgrade to 10 Hz sampling rate, auto calibration and ease of operation. Considerations of dynamics were not exact, but the aspects of models turning 180 degrees in 2 seconds had to be taken into account.

The evaluation concluded that a hydroacoustic, puls-based hyperbolic three dimensional positioning system could be realized within the time and finances available. Designing and developing UPOS consequently commenced august-september 1986.

MEASUREMENT SYSTEM SPECIFICATIONS

In order to anticipate the various possible model experiments at MARINTEK laboratories, the UPOS system had to meet some basic requirements.

Positioning should be global meaning that the entire basin measuring 80 by 50 by 10 metres could be covered without rearranging equipment or having to interrupt experiments. This calls for adequate signal to noise ratios over transmission ranges in excess of 90 metres. It also makes multipath conditions a worst case. On the other hand, this specification has led to developing more of a general purpose instrument than would have been the case if only local coverages had been chosen.

Accuracy down to a couple of millimetres would be required for some purposes. Systems had to operate without electrical connection to a free running model.

In addition to the three transmitters required on the model to enable computation of heave, roll and pitch, a fourth transmitter was requested for cases with chained models.

Limited by multipath noise, using three transmitters in time multiplexing the total sampling rate could not be expected higher than 3 Hz. Sampling rates in the order of 10 Hz can then only be realized using frequency multiplexing of the pingers. Since UPOS was to meet future requirements for higher sampling rates and increased overall accuracy, a modular system evolved, incorporating four frequency multiplexed channels.

UPOS had to be a self calibrating system that could be operated by most members of the staff. This implicated that all hydrophones other than those serving as precalibrated references should be calibrated each time the system was initiated. Clocks in the model transmitter and the receiving equipment had to be automatically synchronized and kept in a constant phase relationsship throughout a typical test period of several days without the aid of a direct connection between them.

SYSTEM DESCRIPTION

System Outline

As shown in Fig. 1 UPOS consists of fixed hydrophones at different sites around the basin. The object to be tracked carries a four channel transmitter with from one to four active transmitting hydrophones depending on the type of measurement to be performed. The fixed hydrophones are equipped with bidirectional preamplifiers allowing transmitting and receiving through the same hydrophone. This is accomplished using only standard coaxial connections to the preamplifiers for simplicity and easy maintanance, see Fig. 2.

TVG amplifiers, detectors and calibration transmitter are housed in one cabinet allowing the most critical analog circuits to be physically located independently of the rest of the equipment. The cabinet allows for 24 hydrophones in 4 channels. This requires 96 TVG amplifiers and 96 detectors. TVG amplifiers are divided into 12 Single Euroboards, each with 8 amplifiers handling 2 hydrophones, each with 4 separate channels. Detectors are divided into 24 single extended Euroboards. One board handles 4 different hydrophones on the same frequency channel. A calibration transmitter power amplifier can be switched to any of the hydrophones. Selections, TVG, listening windows, detections and transmitter exitation are passed between this cabinet and the processor cabinet by various cables that may approach a length of 30 m. A three wire synchronous bus is used to control the listening windows of the detector system. RS422 interface is extensively used.

The processor cabinet consists of two parts; the VME bus and the Motorola I/O bus. Interfaced to the I/O bus are the trig board and the receiver boards. On the VME bus are the I/O cpu board, the cpu boards for mathematical processing and the inter cpu driver board. Each receiver board can handle 8 individual incoming detections. The I/O cpu communicates with the math cpu's via the VME bus. The I/O processor also handles communication with the external host computer through a gpib interface card.

The prototype

The prototype of the system which already has been undergoing some important initial testing is fitted with sufficient components to support 4 transmitters in a time multiplexed configuration using up to 8 fixed hydrophones. The first position tracking trials were done with only 4 fixed hydrophones used each time. Expanding the prototype is made easy by the modular design and can mostly be realized by adding plug in boards since all necessary hardware and wiring are in place. Working frequency of the prototype is 140 kHz.

Design solutions

Various methods of synchronizing the clocks of receiving and transmitting system were reviewed. The principle chosen uses stable clocks (max. 10 ppm) and phase locking of the timebase in the receiving system based on feed back from the mathematical processing.

Calibration software utilizes the ability of pinging with any of the fixed hydrophones. For this purpose both pinger frequency and power are software controlled. This allows reversable distance measurements between any two hydrophones and permits echo sounding measurements to water surface and bottom of basin (Calibrate).

Detectors have approximately a 15-20 dB adaptive range in addition to tvg-regulation. This enables detections with still unknown transmit trig time and is fundamental for detecting when listening windows cannot be predicted, as is the case during synchronization of timebases (Initmob).

To allow future improvements of sampling rates it is required that the pingers can operate simultaneously on separate working frequencies. Each fixed hydrophone should be able to listen to all 4 pingers but detect them individually. Therefore the mobile transmitter is an extensive design using five PAL circuits, yet all is realized on a single eurocard including power output stages. It secures full synchronous operation of all four pingers while permitting independent choices of frequencies, pinging sequences, ping-rates and burst lengths. Thus, the receiving equipment can be expanded to 4 different frequency channels from low frequencies and up to 600 kHz. Selectivity is provided for by analog filtering in order to exclude typical noise accossiated with the use of digital filter types in weak signal applications. This allows for simultaneous pinging and independent detection of up to 4 pingers.

Preamplifiers incorporate a T/R switch to enable pinging and receiving with the same hydrophone and cable.

Switching control of listening windows are sent on a serial synchronous bus from receiver cards to the detectors, one of the receiver boards being the master. This results in simple cabling between the cabinets for the 96 possible individual window settings.

Analog design

Spherical hydrophones of 1/2 inch diameter and resonance frequency at 140 kHz were chosen mainly because of their ruggedness and tollerance to rough handling as would be the case of a protype system. Signal to noise ratios may be optimal when both pinger and receive hydrophones are operated at resonance. The most serious drawback is that all hydrophones should be closely calibrated and selected to avoid unwanted signal variations caused by operating near resonance frequency.

The dynamic range of the TVG regulated amplifiers and preamplifiers are tailored to a range of maximum 100 m and is in excess of 40 db but can be made larger. In addition there is a 15 db dynamic range from the adaptive principle of the detectors. This is achieved by sampling pulse amplitudes within listening windows. The result is a selfstarting detector which very easily locks to the directly travelling pulse.

Digital design

Each detector board hosts 4 analog channels and considerable digital circuitry i.e. one large PAL for decoding the serial window setting informa tions. The board has been successfully realized with four layers in order to avoid onboard noise and crosstalk. The Trig card uses conventional counters and the processor clock to provide a system trig at the same rate as the model transmitter and synchronous with the processor system and system time. A special register allows the trig counter rate to be altered with 62.5 ns resolution permitting software to phase lock the receive system with the transmitters. Other circuitry are TVG generator, function generator for calibration transmitter exitation and control logic. The Receiver board uses a 24 bit counter to measure distances and the results are stamped and stored in FIFO memory where it is read by the I/O processor. Each receiver board handles 8 detections and times 8 window settings to the respective detectors. Both boards uses the available interrupts on the I/O bus. A few of the various boards are shown in Fig. 3.

ACCURACY CONSIDERATIONS

With a system resolution of 9/100 mm and application of zero crossing detection, the accuracy of the distance readings is mainly determined by signal to noise ratio. Calculations have shown that mm precision can be achieved with less than 100 v p-p applied to a spherical hydrophone with the given ambient background noise level. Optimizing for very short pulses prevent multipath distortion in some critical conditions. Fig. 4 illustrates some relationships between hydrophone geometry and redundancy. Erroneous detections degrade overall accuracy but the extensive redundancy from a large number of detections limits this influence. The chance of window predictions being upset by errancy is extremely small since they are a result of xyz precision.

POSITIONING SOFTWARE

This software is installed on a separate cpu board for mathematical processing. The design of the software allows parallel processing on several cpu boards in order to effort real-time processing even for higher sampling rates.

The programming language is Standard C. However, functions for matrix operations and calculations are recoded to Assembly in order to minimize the processing time.

Calibrate/newref

This program supports the self calibration mode. Distance counts between all hydrophones connected to the receiver are used after being prefiltered. A minimum of four hydrophones serve as accurately positioned references. In the Least Squares Adjustment routine the following parameters are estimated:

- acoustic speed in water
- x, y and z (Cartesian coordinates) for receiver hydrophones with unknown position
- variance for acoustic speed and x, y and z
- variance for distance measurements

No approximate positions are required for receiver hydrophones with unknown position.

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Initmob

This is the start procedure for the positioning of the transmitter hydrophone(s). The program solves two essential tasks:

- finding the start position for the transmitter hydrophone(s)
- synchronizing between time base of pingers and receiver time base

No approximate positions are required for transmitter hydrophones. However, the approximate sampling rate have to be known (boot parameter).

Poscalc

When initmob has been run, this main positioning software undertakes the real-time position estimation and support. The algorithm is a 8-state Kalman filter for each transmitter hydrophone. The states refers to the system time when the signal is transmitted:

- x, y and z): models position states
- vx, vy and vz): models velocity states
- b and vb): range bias and clock drift

The two last states are common for all transmitter hydrophones since they are controlled by the same clock.

The System noise appears in two different ways:

- time exponential aging of the covariance matrixes
- noise calculation based upon the residuals of the measurements

Using these thecniques allows both apriori optimal tuning of the filters, based upon the models and the clocks dynamics, and real-time tuning.

The program forces the range bias to zero by controlling the receiver. This gives more confident estimation of the listening windows for the receiver channels.

The software in the UPOS system is made flexible and supports many model configurations and gives the possibility to estimate a rigid models' all 6 degrees of freedom when at least 3 transmitters are located on it. The Kalman filter gives complete covariance matrixes and allows the user to effort intelligent processing on his own computer.

INITIAL SYSTEM TESTS

Results from the first laboratory tests confirms the expected performance of UPOS. Figs. 5 and 6 show results from a dynamic test; circular motion using one pinger with a radius of 1.0 m. The test was carried out with only 4 reference hydrophones and a sampling rate of 2 Hz.

	Fig. 5:	Fig. 6:
Perisph. vel.:	0.4 m/s	1.4 m/s
Centr. acc.:	0.2 m/s^2	2.0 m/s^2

The graphic presentation is disturbed by straight line drawing from one position fix to another.

CONCLUDING REMARKS

It remains to complete the test program which include tracking a ROV with improved accuracy and determining six degrees of freedom. Restricted project economy has temporarily postponed these concluding trials, however, results so far have clearly demonstrated that UPOS will fullfill most of its goals.

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REFERENCES

[1] Hermod Fjæreide, 'DIFFSTAR: A concept for Differential GPS in Northern Norway', pp. 284-295, Navigation, Vol. 33, No. 4.

[2] Nils K. Rossing, 'Forprosjekt: Instrumentering av Undervannslegemer', Rapport No. MT51.9650.00/01/86.

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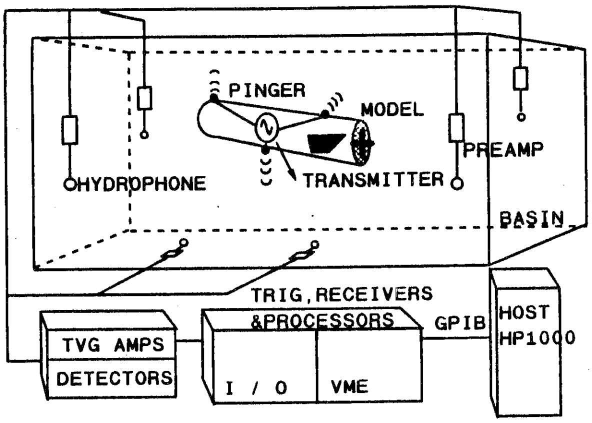


Fig. 1

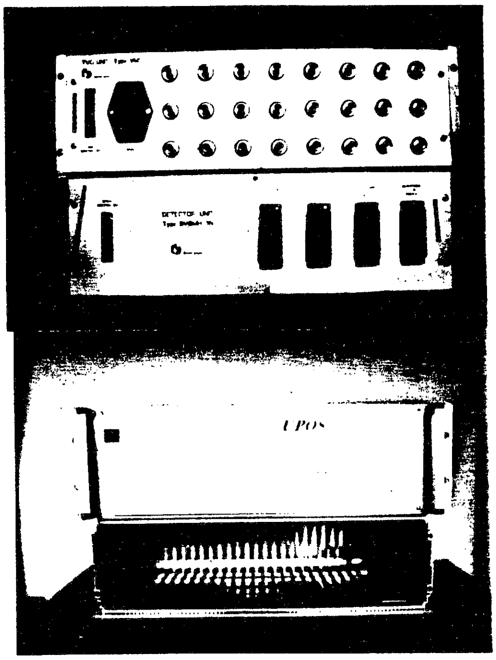
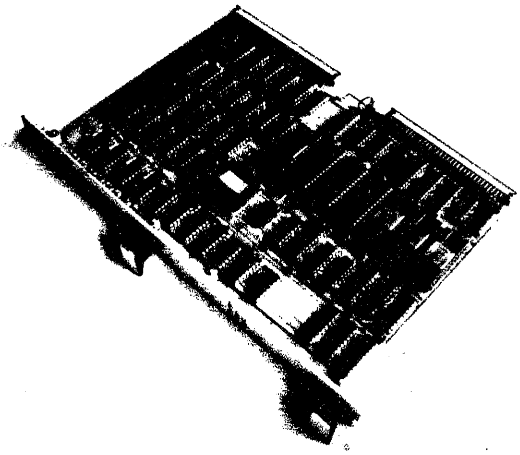
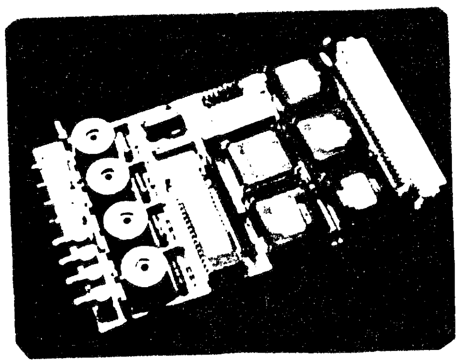


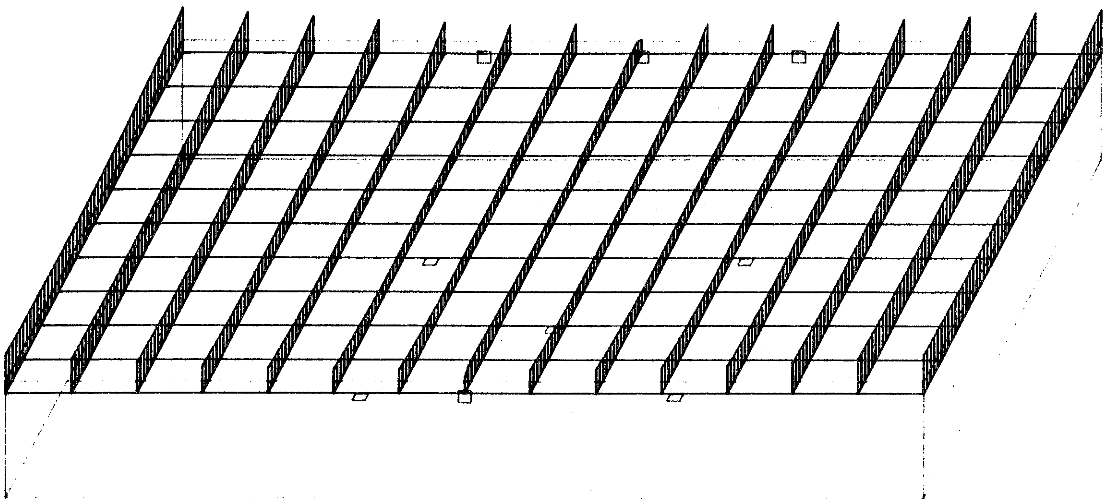
Fig. 2



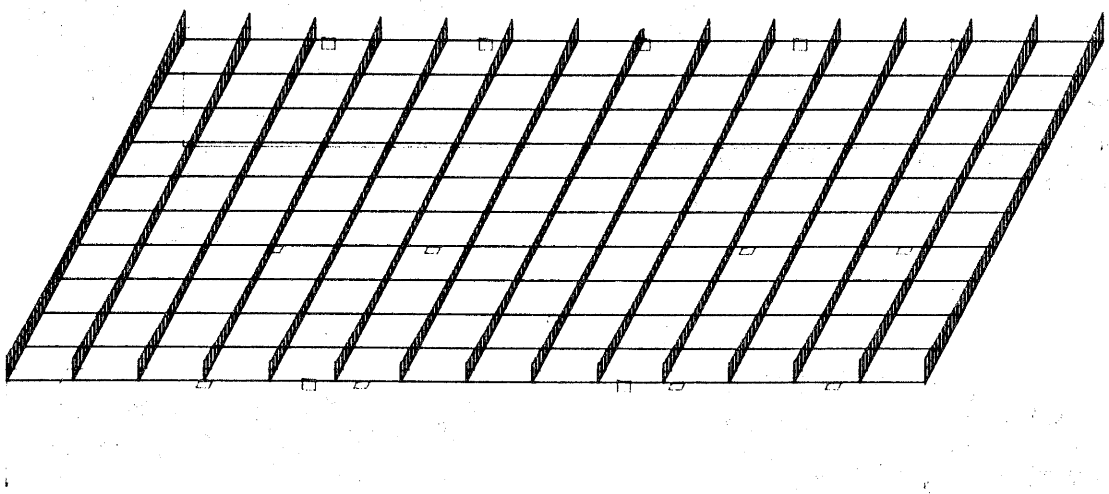
Receiver board



Pinger board
Fig. 3



9 hydrophones



16 hydrophones

Figure 4. System precision versus xy position with pinger at 1 m depth. Squares equal total distance measurements precision and show hydrophone positions on walls and floor of tank. Total depth is 10 m.

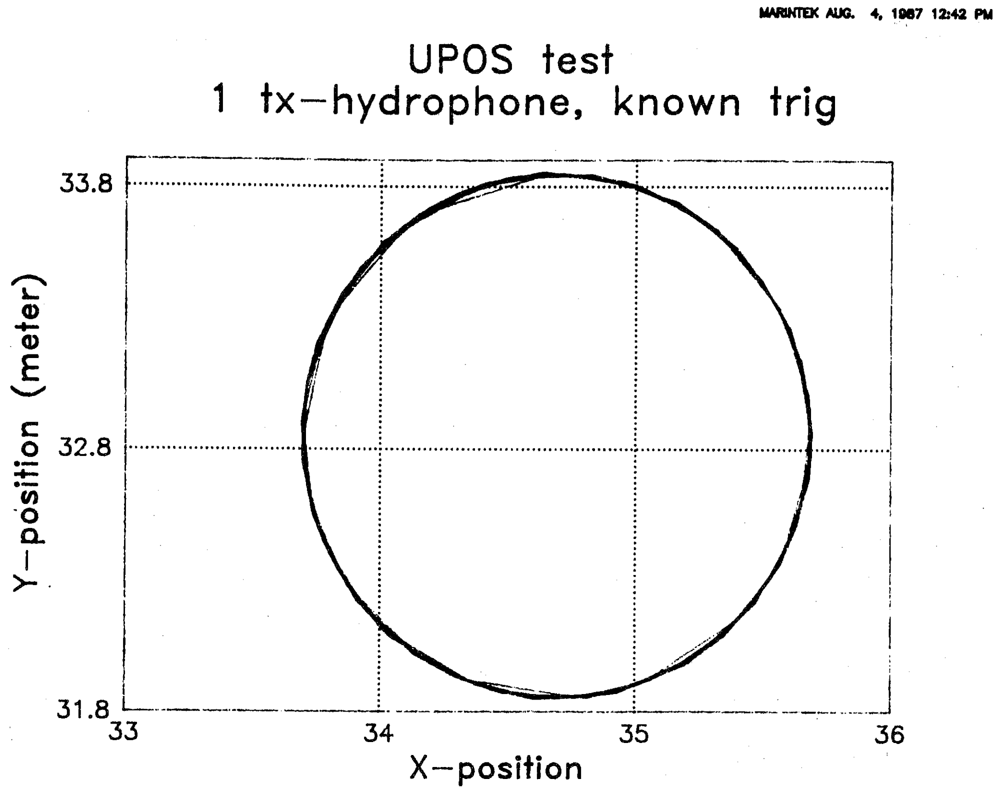


Figure 5.

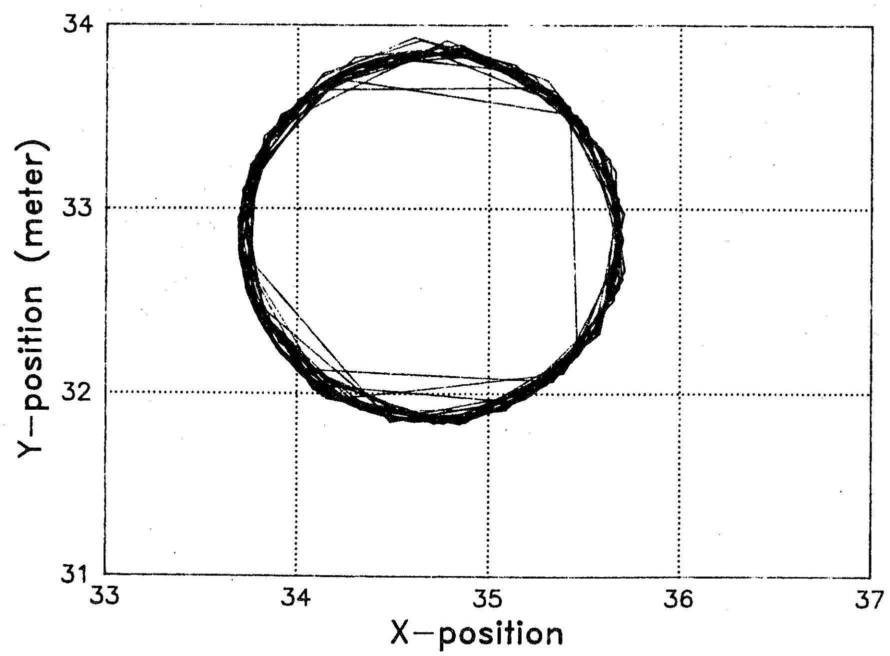


Figure 6.