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HIGH RESOLUTION, MECHANICALLY SCANNED SONAR

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1. INTRODUCTION

The design of sonar equipment for mounting on ROV's is particularly challenging in terms of acoustic specification, packaging size, and electronic design. Use of a micro-processor in the controller can help considerably in reducing size and the amount of hardware design. This, however, may be at the cost of stringent timing constraints, or complexity in software. The sonar to be described here is one of three designed by dB Instrumentation with a central micro-processor controller.

2. CHARACTERISTICS OF A SONAR OPERATING ON AN ROV

In controlling and navigating a remotely operated vehicle near the sea bed, an operator requires advance warning of obstacles. This may be provided by TV if water conditions are suitable, but when the turbidity is high, which is the case in many coastal areas, optical systems have a very short range and effectiveness. Acoustic systems will operate even when the water is very murky. Unless, however, suitably high definition can be obtained from the sonar, sufficient to form a pictorial display, there is no advantage. The first requirement is to define the characteristics of a sonar which can substitute for TV in navigating and examining objects. The sonar must therefore generate a pictorial display, occupy a small size, and be usable at close ranges.

A pictorial display implies both a short pulsed signal and low array beamwidth for high resolution, combined with some form of scanning to cover a wide arc. The constraint of small size implies a high frequency of operation to achieve the angular resolution. Close range operation implies further that the array should be focussed, as its near field will extend well beyond the ranges of interest.

2.1 Vertical Discrimination

One feature of the type of sonar under discussion is that it is essentially two dimensional in operation. The beam of the sonar has a vertical extent, and all objects at the same range, regardless of vertical position, will return an echo. If the sonar is directed forwards and downwards, it is therefore impossible to tell whether an object is resting on the bottom, or just above it.

Vertical discrimination can be provided by allowing the head to tilt so that the greater angular resolution in the main scanning plane can be used to measure height. A scan in the tilt or roll plane is also conceivable, for initial detection and coarse localisation.

3. ACOUSTIC, MECHANICAL AND ELECTRONIC CHARACTERISTICS

Features of the required acoustic, mechanical and electronic performance can be given after considering how the sonar is to operate.

3.1 Positioning System

The positioning system must be capable of training the array to an accuracy much greater than the angular resolution. Since the sonar is to be used as an aid to navigation, the ability to move rapidly between adjacent positions in a scan is very desirable, as this will reduce the time to refresh the display and the information presented to the operator will be more up to date.

3.2 Sonar Electronics

At the frequencies indicated, upwards of 500KHz, sonar propagation is severely affected by absorption. While only short ranges are intended, the signal strength varies over a considerable dynamic range. The receiver channel must be capable of operating at both ends of the range, i.e. to process signals from both close and distant targets efficiently. It is also necessary to transmit significant amounts of power to receive echoes from distant targets.

3.3 Focusing

An array increases signal-to-noise ratio, hence detectability, when individual outputs can be added coherently. In the near field, this implies either delaying or phasing transducer elements electrically or constructing the array along the arc of a circle whose radius is equal to the focal length. Of the two, mechanical focusing is more efficient in its use of space and power.

4. SONAR OPERATION

After the positioning system has trained the array along the required direction, the sonar operating cycle begins with the transmission of a pulsed signal. During the transmission, and for period after, the receiver electronics is turned off to avoid ringing due to activation of the receive array by strong reverberations, and high power feed through from drive electronics.

When the receiver is activated, a time-varying gain is applied to thesummed output of the array, in order to normalise echo strength against propagation loss effects. The time/gain characteristic is of the form

g(t) = (r**4)*(10**2ar), where
r = ct/2, c = speed of sound,
t = elapsed time,
a is absorption/unit distance.

This comprises a linear section at very close range, followed by an exponential section extending out to long range.

Unless the operating parameters are fixed, which is unusual, as even pulse width may need to be changed to trade off resolution against detectability, there is an overhead on each cycle involving the setting up of the system.

5. USE OF A MICRO-PROCESSOR

The several functions described could well be carried out by a system based purely on a mixture of analogue and digital electronics. The requirement of small overall size, however, directs attention to use of a micro-processor as overall controller, to save on the volume of electronics, and complexity of design. If basic functions are under the direct control of a computer, much greater flexibility in operation is also possible, including, if required, the execution of a stored sequence of cycles.

The question arises of whether to design from component level up, or use proprietary boards. The choice rests both on the selection of micro-processor, and the aim of the project. For prototyping, there is little doubt that proprietary boards are the better choice, provided that design aims are not compromised. In support of this, consider that there is no development time, and spares are more readily available should damage occur. The trade-off is that there may be unused functions which are being paid for unnecessarily. However, the cost penalty is much less than design cost, and the currently excess capacity may turn out to be an advantage in future expansion. In the system to be described, which uses three boards from the VECTOR INTERNATIONAL Euro-card range, it turns out that there is little overhead in excess capacity.

6. DESCRIPTION OF THE MECHANICALLY SCANNED HIGH RESOLUTION SONAR

In order to discuss the subject further, it is necessary to give ranges for the main parameters of the sonar. Some details of the design, reasons for choices of options, and how the micro-processor hardware and software forms the essential part of the controller will then be given.

6.1 Broad Specification

Carrier frequency has been given as greater than 500kHz. Angular resolution should be better than a degree for a postulated operating range of 0-100m. Pulse widths down to 100's of micro-seconds should be available.

The displayed sector can be as wide as desired, but there is a trade-off between time to complete a scan, and forward speed of the vehicle, and in addition, at large angles to the forward direction, the range ahead of the vehicle is much reduced. The solution adopted in the present system is for a large possible coverage, of which only a part is used at any time.

6.2 Micro-Processor Functions

The system under consideration gives all control functions to the micro-processor, including

- gating the carrier for the transmission
- switching the receiver on and off
- supplying the control voltage for the time varying gain
- closing the loop on the azimuth servo
- supplying the reference voltage to the roll servo.

It is itself programmed by an operator via a serial setting interface, which allows it to be readily integrated into an automated system. For stand-alone operation, a small micro-based station has been developed, allowing an operator to transmit commands and receive numerical status information.

6.3 Hardware

The controller consists of just four Euro-card boards, three of which are proprietary boards on the bus of the micro-processor. The fourth is a purpose designed sonar electronics board, which interfaces through I/O ports. As already mentioned the micro-processor boards are from the standard MMD16 range of VECTOR INTERNATIONAL, which use the INTEL 8088 micro-processor. This gives the advantage of 16 bit operation internally, with the smaller size requirements of an 8 bit data bus.

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As well as the general advantages of using proven sub-units and ease of starting up in a prototype design, these boards have the further attraction of being burnt in for a month before delivery, and are constructed to military standard, having a NATO part number. A list of the controller boards, with VECTOR part numbers where appropriate is as follows:-

MMD16-88P	-	CPU;	MMD16-IOW - parallel I/O
MMD16-DA12	-	D/A;	Sonar Electronics

6.4 Allocation of Hardware

Referring to the section on sonar operation, and taking each stage in turn, a brief functional description the hardware follows.

6.4.1 Positioning

Movements in roll and azimuth are controlled by output of a voltage through D/A, although the means of closing the loop is different in each case. Each servo is switched on and off by altering the sense of lines on the IOW board, and in both cases, the state of the servo loop is measured by reading data from lines on the IOW board. The azimuth servo loop is closed by the micro, which reads the current angular position measured by a 12 bit resolver. The roll servo loop is closed electronically. The state of the loop is defined coarsely as out of tolerance, and in tolerance 1 and 2, and changes when the difference voltage crosses one of two thresholds.

6.4.2 Sonar

The sonar transmitter is switched on by setting one of the lines on the IOW board high, and off again by resetting. The receiver is switched off simultaneously, with switching on the transmitter and switched off at a later time.

The durations of both transmission and receiver blanking periods are determined by reading the counter on the CPU board which clocks at 62.5µS. This was felt to be a sufficiently small interval for the purpose, especially given space constraints, although there is a compromise on the rate of updating the gain at very close range. If a smaller basic interval had been essential, a standard timer board clocking at much faster rates could have been used.

The time varying gain curve is approximated by a stair-case function. Length of each step and the gain change are stored as tables in the memory of the computer. The gain control voltage is output through a D/A. Time is compared to elapsed time measured by one of five timers in a MUART on the MMD16-88P board, and when next update time is equal to current time, the gain voltage is output. Gain is matched to 0.25dB of nominal except at very close range where a faster update rate than 16kHz is called for.

6.4.3 Communications

The serial I/O on the board is selected as RS232, although a 20mA loop is available. Baud rate and number of bits/character are set up by programming the MUART on the MMD16-88P board by software. Received characters are buffered into the RAM of the CPU.

6.4.4 Other Functions and Spare Capacity

One of the D/A's is used to provide a reference voltage to the rest of the system. There are 16 parallel I/O lines unused on the CPU board.

6.5 SOFTWARE

The software is written in modular form for ease of maintenance and testing. It has three levels of control. At the highest level, the overall sequencing of operations, and setting of the system takes place. The next level is the functional level, where the processes involved in positioning, communications, and sonar operation are executed. At the lowest level are the peripheral interfacing sections of the program.

This is a real-time application. If those sections of the program under this constraint could be run one after the other, there is sufficient processing time to meet the requirement, and the coding would be relatively straightforward. This, unfortunately, is not possible, and sharing of processing between real-time activities is necessary. Writing a real-time scheduler to achieve this has been the most demanding part of the sofware development.

In line with current trends to-wards the use of high level languages, an initial design aim was to use PASCAL for all but the very hardware dependant operations such as system initialisation and I/O device handling. It has proved impossible to keep to this as timing constraints on program execution have emerged during detailed design. The only sections of the software eventually written in PASCAL were the highest level main program, and a procedure directing operator communications.

6.5.1 Real Time Operations

Serial I/O is at a relatively slow rate, with one character every 520 µs at a rate of 19200 baud (10 bits/character). The normal clock rate of the MMD16 bus is 5MHz, at which a simple I/O operation takes 2 µs. This leaves more than enough time for overhead activities.

The azimuth servo loop has a bandwidth no greater than 200 Hz. To avoid aliasing problems in the loop, an update rate of ten times this was specified. This implies a processing interval of at most 500 µs between making corrections to the angular position. There is sufficient time to achieve the result with time for overhead.

Sonar channel control involves reading time increments and, for the TVG, gain increments, from tables set-up to cater for the particular pulse width and range scale in use. While the margin is small at the fastest rate of 1 update per timer increment, it is still possible to achieve this performance and to match the ideal TVG curve as closely as the quantisation in time will allow.

6.5.2 Time-Sharing

Once the head is in position, acoustic operation can take place. Due, however, to the presence of disturbing forces on the head caused by movement of the ROV, it is also necessary to hold the array in position while echoes are being received. Neither servo control software nor sonar control sofware can be run alone as single functional units during this period.

The approach adopted to meet this need involves writing small units of code, each performing a single operation. For the servo function, the units were

- check if in tolerance
- switch on servo
- output demand, and carry out further check
- switch off servo
- check for overshoot.

For the sonar function the units were

- trigger transmitter and blank receiver
- switch off transmitter
- switch on receiver
- set up next gain and output.

Sonar program units must be executed in a defined order at times determined from the pre-stored tables, whereas servo functions must be performed at certain rate, but in an order which cannot be determined precisely in advance. This is due to the unpredictability of the effects of external forces which, depending on conditions, will produce varying rates and magnitudes of disturbance in position.

6.5.3 Real-Time Scheduler

The algorithm used to allocate CPU execution time to program units uses two program state variables, one for servo program units, and one for sonar units, in conjunction with measurement of time elapsed from start of transmission. These variables describe the behaviour of the system, for example whether it is out of tolerance. The value of each state variable determines which program should be executed next.

As a result of the execution of a procedure, the state variable will be modified, and it has been arranged that each procedure returns a value, which is used to determine the new state of the system. The sonar system state variable will increment until the TVG update sequence begins, and remains fixed until the time passes the maximum range travel-time. The variation of the position state variable depends on the result of the current measurement procedure. It will be unaltered both while the head remains in position or while it is being moved.

After each program unit returns control to the scheduler, the timer is read and the amount of time left before the next gain update is calculated. While there is sufficient time to execute the longest servo program, this time being determined during development, the CPU is devoted to servo control, even if this merely involves repeatedly confirming that the head is in position. When to execute another servo program unit would overrun the time for the next sonar output, the scheduler hands over to a sonar procedure which runs a waiting loop until that time has been reached. After the sonar action is complete, the positioning loop resumes.

7. CONCLUSION

This project has been an ambitious one in terms of both acoustic and controller performance specification. It has been demonstrated that a design based on commercially available boards is feasible, without penalty. The software design has proved to be more demanding, but the simple real-time executive developed for this purpose is sufficiently general to be used in other applications outside acoustics.