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TITLE

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A compact, low-cost computer interfaced video positioning system

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Contract #W7707-00813/001/HAL

Scientific Authority: F. Deshamais (902-426-3100)

Defence R&D Canada
Contractor Report
DREA CR 2001-198
December 2001

National Defence Défense nationale

Canada

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Author

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Approved by

12/07/2002

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Abstract

An optical positioning system was designed to measure the shape of a hydrophone array underwater. The prototype used a small sensitive black and white camera as the positional detector and high intensity light emitting diodes (LEDs) as tracking targets. The system was examined for its potential range capabilities and spatial resolution underwater. Tests were conducted specifically on the range limits of the system in both freshwater and seawater. The results suggested that the system allowed target positions to be determined at ranges up to 65 m from the camera with a lateral accuracy of 26 cm. They also indicated, however, that water-born attenuators could dramatically reduce the system's operational range limit. Field tests in near-shore waters of Nova Scotia found ranges that were closer to 20 metres at the time of the tests with the expected lateral accuracy.

Résumé

Un système optique de positionnement a été conçu pour déterminer la forme d'un réseau d'hydrophones sous-marins. Dans le prototype, une petite caméra noir et blanc sensible a été utilisée comme localisateur, et des diodes électroluminescentes (DEL) à haute intensité servent de cibles. Un examen a été mené pour déterminer la portée et la résolution spatiale du système sous l'eau. Plus particulièrement, les essais portaient sur la portée limite du système, tant dans les eaux douces que les eaux de mer. Les résultats laissaient supposer que le système permettait de déterminer la position de cibles à une distance pouvant aller jusqu'à 65 mètres de la caméra avec une précision latérale de 26 cm. Toutefois, ils indiquaient aussi que des atténuateurs marins risquent de réduire considérablement la portée opérationnelle limite du système. Lors d'essais effectués dans les eaux à proximité du rivage de la Nouvelle-Écosse, la portée se situait plutôt aux alentours de 20 mètres au moment des essais avec la précision latérale prévue.

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Executive summary

Oceanographic measurements made with mooring technologies are often plagued by the action of ocean currents upon the cables or ropes used to secure instruments at depth. These cables, ropes, or harness assemblies drift, and or, strum in response to the friction and velocity of water flowing by them. For underwater acoustics work, knowing the precise position of individual hydrophone along an array is often critical.

Several solutions exist to estimate the position of moorings as a function of time, the traditional technique using depth and tilt sensors distributed along the array. These solutions, however, are often expensive, power consuming, or otherwise inadequate to fully describe the 3-D shape and motion of the array.

It has only been in the past decade that low-cost surface-mount digital processing systems and associated electronics have become economical. This availability has lead to the development of simplified, smaller, and more powerful sampling and processing electronics, some of which could serve together to create a low-cost, low-power, positioning system. The conceptual system determined the shape of an underwater mooring by positioning tracking targets mounted at fixed points along the mooring. The prototype used a small sensitive black and white camera as the target localizer and high intensity light emitting diodes as tracking targets. The system was examined for its potential range capabilities and spatial resolution underwater.

The results suggested that the spatial resolution of the system was better than 26 cm with target ranges as great as 65 metres. They also indicated, however, that water born attenuators could dramatically reduce the systems operational range limit. Field tests within near-shore waters of Nova Scotia, for example, found range limits closer to 20 metres.

The system showed strong potential for use in small, low-power acoustic systems, such as Rapidly Deployable Systems.

Dittman, R.D. 2001. A compact, low-cost computer interfaced video positioning system. DREA CR 2001-198. Defence Research Establishment Atlantic.

Sommaire

Les mesures océanographiques effectuées au moyen de technologies d'amarrage sont souvent faussées par l'action des courants océanographiques sur les câbles ou les cordages utilisés pour fixer les instruments aux fonds marins. Ces ensembles de câbles, de cordages ou de faisceaux dérivent ou vibrent en raison du frottement et de la vitesse des courants d'eau. Dans le cadre du travail acoustique sous-marin, connaître la position précise d'un hydrophone donné faisant partie d'un réseau est souvent indispensable.

Il existe plusieurs solutions pour estimer la position des amarrages en fonction du temps; la technique classique consiste à utiliser des capteurs de profondeur et d'inclinaison répartis le long du réseau. Cependant, ces solutions sont souvent coûteuses, consomment beaucoup d'énergie ou ne permettent pas de décrire complètement la forme 3D et le déplacement du réseau.

C'est seulement au cours de la dernière décennie que les systèmes de traitement numérique montés en surface et bon marché et les éléments électroniques connexes sont devenus économiques. La disponibilité de ces systèmes a permis de développer des dispositifs électroniques d'échantillonnage et de traitement plus simples, plus petits et plus puissants. Certains de ces dispositifs peuvent être utilisés ensemble pour créer un système de positionnement peu coûteux et à faible consommation d'énergie. Le système conceptuel a permis de déterminer la forme d'un amarrage sous-marin en fonction de la position de cibles posées à des points fixes le long de l'amarrage. Dans le prototype, une petite caméra noir et blanc sensible a été utilisée comme localisateur de cibles, et des diodes électroluminescentes à haute intensité servent de cibles. Un examen a été mené pour déterminer la portée et la résolution spatiale du système sous l'eau

Les résultats laissaient supposer que la résolution spatiale du système dépassait 26 cm, et que les cibles pouvaient être situées jusqu'à 65 mètres. Toutefois, ils indiquaient aussi que des atténuateurs marins risquent de réduire considérablement la portée opérationnelle limite du système. Lors d'essais effectués dans les eaux à proximité du rivage de la Nouvelle-Écosse, par exemple, la portée limite se situait plutôt aux alentours de 20 mètres.

Le système pourrait convenir à l'utilisation dans les petits systèmes acoustiques à faible puissance, comme les systèmes à déploiement rapide.

Dittman, R.D. 2001. Un système de positionnement compact et économique basé sur un signal vidéo connecté à un ordinateur. DREA CR 2001-198. Centre de recherches de la défense Atlantique.

Table of contents

Introduction

This report describes the design and testing of a prototype optical positioning system designed for DREA to estimate *in situ* shape variations in hydrophone arrays. The system first described in a previous DREA contract, utilized off-the-shelf video technology coupled through a computer interface to a logging and presentation device such as a laptop personal computer. The system determined array shape variations by mapping the 3-D spatial coordinates of high intensity light emitting diode (LED) targets mounted along the length of the array. Target coordinates are derived through their location within the image of a video camera and the depth separation between the camera and the specific target. The system was a hybrid analog/digital system employing a high sensitivity black and white video camera as the spatial sensor, a counter module to position select targets in the video frames, and an interface computer to synchronize and download count information from the counter module to a personal computer. The single chip interface computer was also responsible for driving the pulse timing of the camera and the LED strobe so that the strobe flashes in synchrony with the frame timing of the pulsed camera. The result is a low power system, drawing 550 milliamperes, but only during an 80 millisecond pulse. The system was therefore, ideally suited for battery run operations. The low current requirement coupled with the system's compact size allows it to be easily incorporated into compact packages within existing hydrophone array systems. Data outputted from the system is in a standard ASCII format with the 3 variables describing the coordinates of the targets within the field of view of the camera as a function of time.

The Prototype

Six major components comprised the system: 1) the target strobe, 2) the camera module, 3) the video/ counter module, 4) the micro-controller computer, 5) the video monitor, and 6) a laptop personal computer for data logging. The target strobe which used 4 focused, high intensity blue LEDs pulsed with a total peak current of 430 milliamperes for a duration of 32 milliseconds. The strobe module had its own pressure transducer and was powered from the surface through an umbilical cable. The camera module also had an independent pressure transducer and, was interfaced and powered independently through its own umbilical cable. The raw video signal was passed through a 75 ohm coaxial cable to the video/counter module where it was broken into its component synchronization signals.

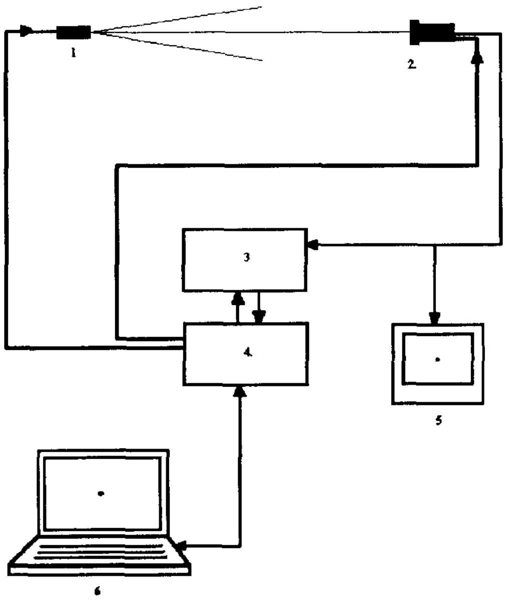


Figure 1: A schematic flow diagram of the positioning system showing the 4 main components: (1) the LED strobe target, (2) the camera, (3) the counter module, and (4) the interface/ control computer. The schematic also shows the video monitor (5) and the display and logging computer (6).

Three main components of the video signal were isolated using operational amplifiers as comparators (See Figure 2). They were: 1) the raw CCD output, 2) the video frame synchronization pulse, and 3) the line synchronization pulse. The different signals were converted to positive going TTL level pulses and sent to the counter module. Spatial coordinates were derived through counters (Fairchild 12 Stage Counters MM74HC4040) in the counter module. Frame, and line sync. pulses were used to zero counters while a series of latches (Fairchild D-Type Edge Triggered 3 State Octal Flip Flops MM74HC574) sampled count values when triggered by the strobe peak image. The vertical axis of the video image was derived through counts from a 63 kHz clock signal and were reset at the beginning of each frame through the use of the video frame synchronization pulse.

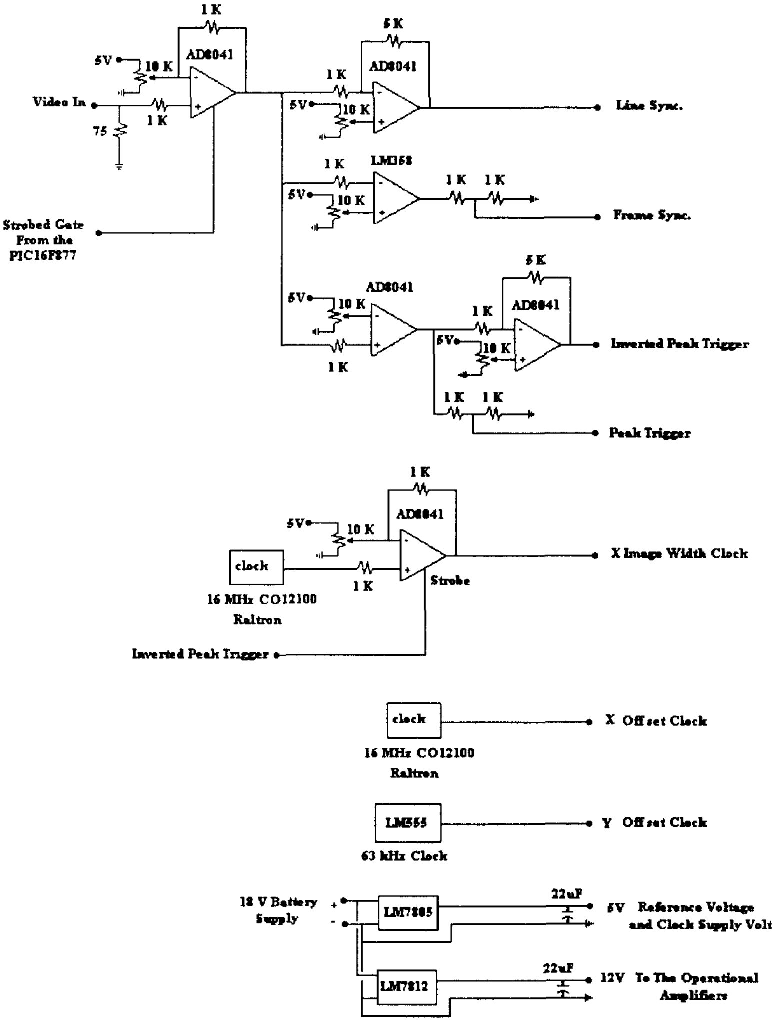


Figure 2: An electronic schematic diagram describing the way the raw video signal from the video camera was broken into its component signals and converted to TTL level signals for the counter module.

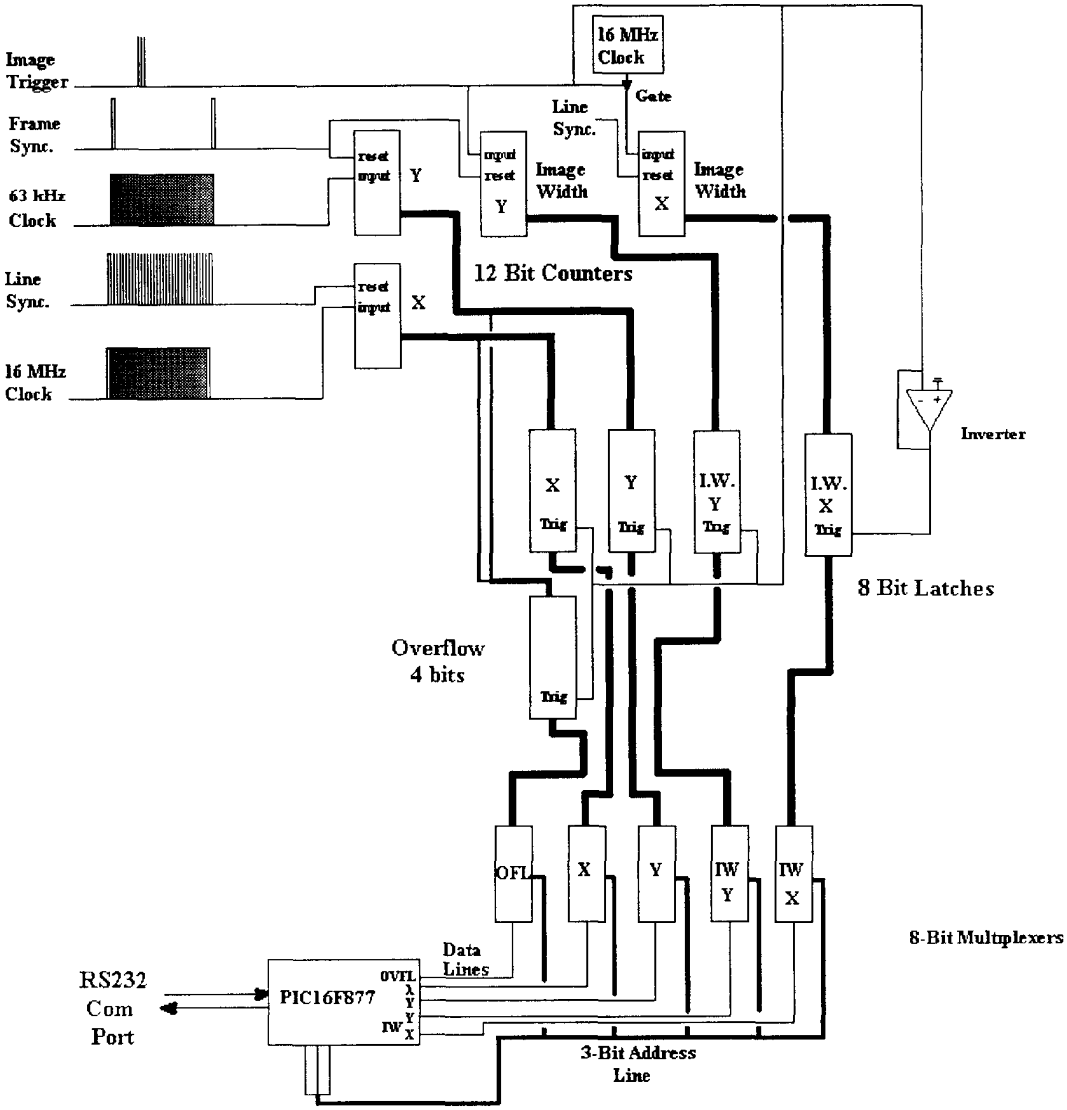


Figure 3: A schematic diagram describing the sampling of the conversion of the video signal into the spatial coordinates of the LED targets viewed by the camera.

Within each line, counts were paced using a 16 MHz clock. In both the vertical and horizontal axis the number of clock pulses within the period of a frame and a line were in excess of the actual CCD pixel dimensions. This allowed for a certain amount of averaging on the edge of the target peak. In the vertical axis the number of clock pulses per pixel was 2.65 while in the horizontal axis the value 1.56 (using a 380x512 pixel

CCD). Counts were measured between the leading edge of the sync. pulses and the leading edge of the last line with a peak associated with the strobe image. The y-value of the image center was derived by subtracting half the image width or the number of lines containing image peaks divided by two, to the y count. The x value was estimated by adding a proportional image width in the x dimension since the count was recorded on the leading edge of the image peak. The y value in contrast was recorded for the falling edge of the peak. In this scenario the image was assumed to be circular in shape and the best estimates of the target center would be obtained when the image width was near a minimum, i.e. a single pixel. Typical image widths however, were near 8 pixels.

The 10 bit latched counts measuring the frame and line offsets, and the 8 bit image width counts were interfaced through 4 separate 8 bit addressable multiplexers (Fairchild SN74LS251) to 4 separate I/O lines of a parallel port on the PIC microprocessor. The frame counter had a dedicated 8 bit latch and 2 overflow bits on a separate 8 bit latch which it shared with the line counter. The image width counter had its own separate 8 bit latch. Together, the results of each of the 4 latches were sampled by the PIC16F877 chip through 4, 3 bit (total of 8 addresses) addressable multiplexers. These multiplexers allowed parallel access to the 8 bits of the 4 latches and gave the PIC16F877 the ability to sample 32 bits using only 4 lines of its I/O port.

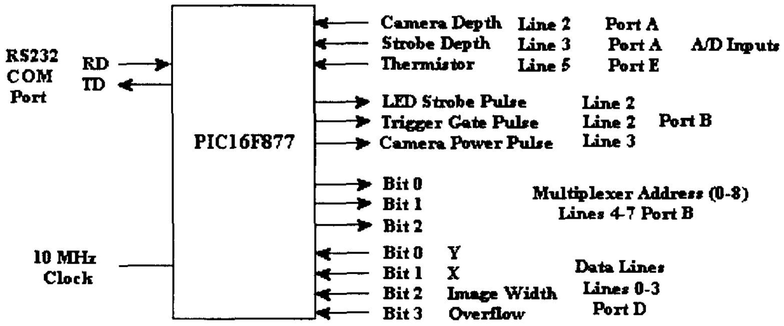


Figure 4: A schematic diagram of the PIC16F877 computer chip showing the respective pin outs used.

The interface module, comprised largely of the PIC16F877 and its peripheral electronics was a fully autonomous computer which activated its program upon power up. The module had a serial RS232 port through which commands could be passed down from a higher computer and the data, returned. In the system controls were passed from the personal computer to the PIC computer to strobe the target and camera and return the respective counts along with the voltages from two pressure transducers. The interface was controlled through a compiled basic program which also stored and presented the data in a graphical format. The basic control program could be executed upon any DOS based computer and required only the RD (Receive Data), TD (Transmit Data), and ground pins of a serial port with a 9 pin connector for communications to the PIC computer. In the deck unit, the video signal could also be displayed upon a television monitor to check for extraneous images.

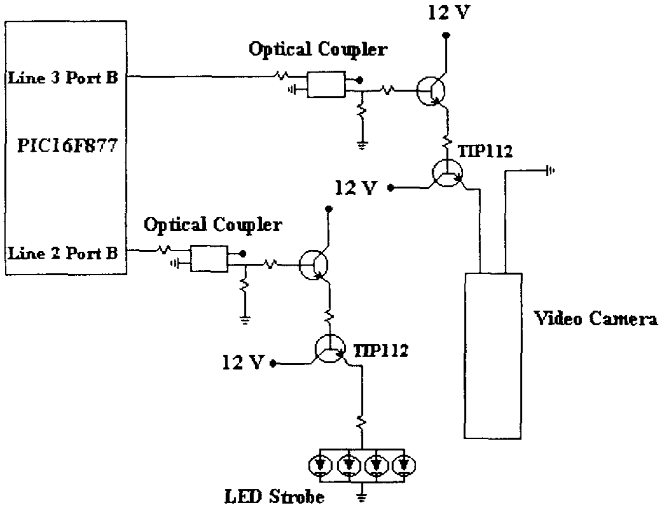


Figure 5: A schematic diagram showing the use of the PIC16F877 to drive the pulsing of the video camera and the LED strobe module.

To test the capabilities of the system, a series of laboratory and field experiments were carried out. Laboratory testing involved simple positioning of a small LED target within the field of view of the camera. In these tests the LED was placed within a few centimetres from the camera window. The scatter associated with the noise of the system was then measured with the LED held fast within the field of view of the camera. The LED was then moved along a single axis using a single axis translation stage and it position recorded during translation. The camera was then rotated around its longitudinal axis so that its view also became rotated. The LED was then re-translated between the limits of the camera's field of view and the line recorded over the previous line. By repeating this several times, a star pattern revealed the center coordinates of the camera's matrix. These coordinates were then latter used to correct the origin of the camera's sampling axis since the bearings to the targets would have to be calculated from this origin.

Field testing of the system was carried out aboard CFAV Quest on Emerald Bank off the coast of Nova Scotia during August of 2001. During this cruise the system was deployed from the side of the vessel to depths of as great as 35 metres. During testing, the camera was lowered first to a depth of 6 metres. The strobe was then lowered through an eyelet on the camera module to a depth below the camera, near the detection limit of the camera and triggering circuit. This was found to provide a range of approximately 17 metres in waters above the thermocline. Within the limits of the thermocline, the effective range of the system was reduced to a value closer to 8 metres or nearly a factor of two reduction.

Results and Discussion

The results of the laboratory testing in which a single led was used as a target showed that the system could be functionally tested and calibrated in the laboratory before deployment with only a minimal amount of cost and labour. The stationary target results showed that the data of the coordinates were tightly clustered with deviations on the order of 1 pixel in the vertical and 0.5 pixels in the horizontal (See Figure 5). The results of the tracking tests also confirmed the systems ability to log target position .

Figure 6 for example presented the results of moving the LED target along a fixed axis while recording. In the figure the data showed off-axis deviations on the order of 1 or 2 pixels depending upon the axis. The scatter in the x axis for example was nearly twice that of the y axis. This discrepancy may in part be the result of the difference in the number of counts per pixel associated with the different axis of the image. The y axis for example used a counter frequency which provided 2.8 counts per pixel while the x axis was subdivided with a counter frequency which provided only 1.6 counts per pixel. If the source of the error was random and was proportional to the number of counts, then it would decrease relative to the clock frequency used. This seemed to be the case here, suggesting that the error was attributable to some form of miss-counting by the counters or electro-magnetic interference on the outputs of the clocks or the inputs to the counters.

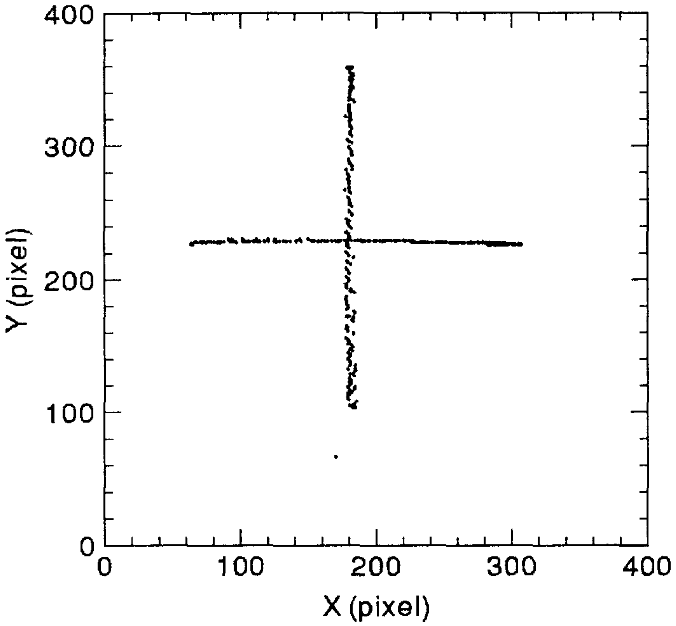


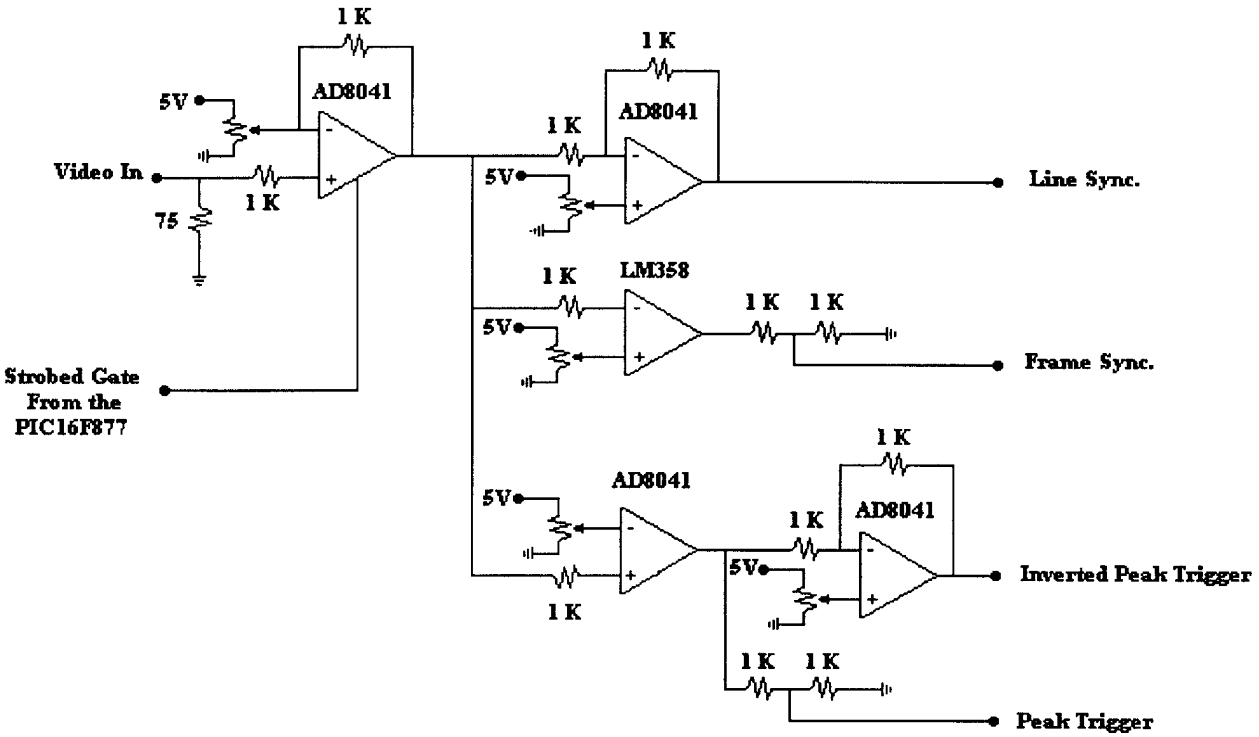
Figure 6: A plot of a series of target coordinates obtained by translating a 3 mm LED at an axial distance of 3.5 cm from the camera, first along the x-axis and then along the y axis of the camera's view.

In addition to the scatter in the data a slight non-linearity could also be resolved. The non-linearity, although small inflected upwards on either end of the LED's transect parallel to the x axis and to the right when paralleling the y axis. This was believed to be the result of stretching of the LED image as it approached the edges of the camera's field of view. This stretching would result in an error in the positioning of the center of the target which is assumed to be circular across the camera's view.

The results of the field trials at sea confirmed that the system could position the strobe in the open ocean at ranges in excess of 10 metres. They also suggested that open ocean range limits would be expected to be on the order of 15 metres and were close to those measured during the sea trials in Bedford Basin during December 2000 and January 2001. They did however, confirm that attenuation factors within the thermocline would limit detection ranges within this portion of the water column. The scatter of the strobe positions in the plots during deployment were greater than those obtained in the laboratory and this was attributed to the large amount of ship motion and waves present (1-2 metres swells) at the time of deployment. The strobe could be seen to jog in and out of alignment with the camera when viewed through the video monitor. One of the most notable results of the field deployments of the strobe was how the shape of the beam image appeared to vary with the motion of the strobe and the amount of scattering particles in the water. Since the image is assumed to be a circle, irregularities in the beam image's shape will contribute to the error in the positioning of the center of the target. This suggests that the closer the strobe is to the camera, the greater its error from image size and shape. In the video images obtained for the same projector used here but deployed in Bedford Basin in January 2001, the beam pattern could be seen to vary as the projector moved in and out of alignment with the camera. When the projector was on axis with the projector, the image appeared as a cloverleaf or a single spot from an individual LED. When viewed off axis, the beam was shown only by scattering off of particles in the water and took the appearance of a comet. The same images could be seen in the video monitor during deployment from the CFAV Quest. These variations were only seen when using the second projector design which has a focused beam. The first projector design lacked the forward beam intensity but had a circular image when viewed by the camera. The best localization will likely be obtained through some hybridization of the two approaches. In the present strobe design, four large LEDs are used as a light source. In future designs a larger number of smaller LEDs could be mounted in a spherical fashion to generate even illumination over the full forward range of angles. The result would provide an image in the camera similar to that seen in the first projector design but would have a greater illumination at the off angles.

Conclusion

In conclusion, the positioning system has been shown to be a functional way to estimate the three-dimensional coordinates of an illuminated target in the open ocean. The primary limitation is the optical range of the target relative to the camera and this is dictated by the attenuation properties of the water column. This can be overcome in part through the use of serial sets of the cameras and LED targets along the length of an array. These would be referenced to one fixed location likely at the base of the array. The minimum spacing between the targets and cameras will be dictated by the normal attenuation properties of the water column but will likely be near 10 metres to ensure consistent triggering of the sampling latches. Given the low costs and power requirements of the actual systems, i.e. camera, strobe and counting circuit, this should be an effective way of tracking an array of any given length.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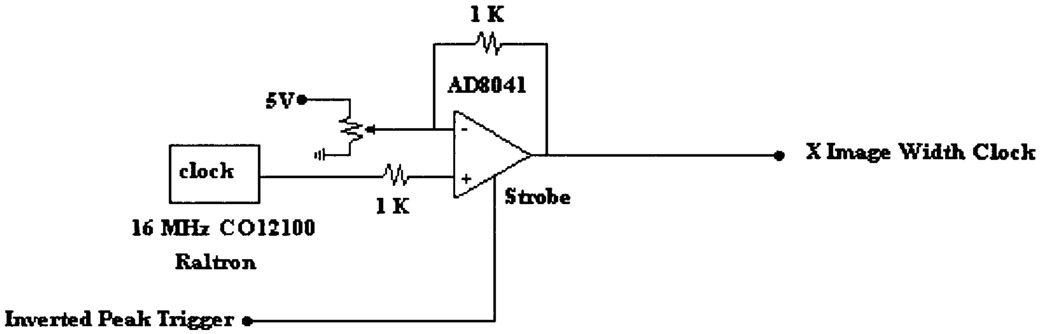
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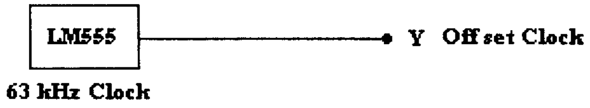
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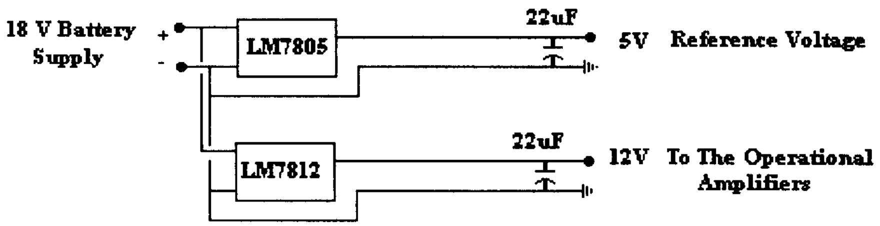
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An optical positioning system was designed to measure the shape of a hydrophone array underwater. The prototype used a small sensitive black and white camera as the positional detector and high intensity light emitting diodes (LEDs) as tracking targets. The system was examined for its potential range capabilities and spatial resolution underwater. Tests were conducted specifically on the range limits of the system in both freshwater and seawater. The results suggested that the system allowed target positions to be determined at ranges up to 65 m from the camera with a lateral accuracy of 26 cm. They also indicated, however, that water-born attenuators could dramatically reduce the system's operational range limit. Field tests in near-shore waters of Nova Scotia found ranges that were closer to 20 metres at the time of the tests with the expected lateral accuracy.

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Positioning system

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