U.S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA

This is a working paper giving tentative information about some work in progress at NEL. If cited in the literature the information is to be identified as tentative and unpublished.
PAIR (AN/SQQ-23) COMPENSATION FOR OWN SHIP's MOTION ON THE SEARCH DISPLAY

by

J. G. Lamb

Code 2140

U. S. Navy Electronics Laboratory
San Diego, California 92152

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This technical memorandum represents a portion of the work being done on NEL Problem J714, AN/SQS-23 Performance and Integration Retrofit (PAIR) Program. It should not be construed as a formal report as its primary intent is to present some of the problems confronting project personnel and some of the preliminary conclusions. While it was originally published in a different form, it is now being included in the technical memorandum series for sake of documentation uniformity and control. Limited outside distribution is intended.
PAIR: Compensation for Own Ship's Motion on the Search Display

INTRODUCTION

Retention and display of echo return history allows the sonar operator to see what areas of the ocean consistently send back echoes, indicating the probability of a target.

Own ship's motion causes the returns to be displayed at different points as time progresses and the echo indications associated with a single target may be so widely separated that the operator fails to correlate them.

The combination of moderate ship speeds, in the order of 15 knots, and long periods between pulse transmissions as in the proposed non-alerting search-track modes may cause a five period history to be dispersed over 8 or more range bins or 4 bearing bins even with a stationary target.

Investigation of the results and feasibility of compensation for own ship's motion on the search display seems justified.

1. Echo return time computation:
   \[
   \text{If sound velocity} = 4800 \text{ ft/sec} = 1600 \text{ yd/sec} \\
   \text{Echo return time} = 2 \times \frac{1}{1600} \text{ sec/yd} = 1.25 \text{ ms/yd}
   \]

2. Ships motion computation:
   \[
   \text{If ships speed} = 15 \text{ knots/hr} = 30,000 \text{ yd/hr} \\
   \text{Motion} = \frac{30,000 \text{ yd}}{3,600 \text{ sec}} = \frac{81}{3} \text{ yd/sec}
   \]

3. Range bin size:
   \[
   \text{Bin size} = \frac{\text{Range Scale}}{48}
   \]

\[
\begin{array}{l|l}
\text{Scale} & \text{Bin Size} \\
2.5 \text{ Kyd} & 52 \text{ yd} \\
5 \text{ Kyd} & 104 \text{ yd} \\
10 \text{ Kyd} & 208 \text{ yd} \\
20 \text{ Kyd} & 416 \text{ yd} \\
40 \text{ Kyd} & 832 \text{ yd}
\end{array}
\]
PAIR: Uncompensated Motion - Range Scale Relations

Simple transmission modes

Echo time per yard of range = 1.25 ms

Own ship's speed = 15 kt = $\frac{81}{3}$ yd/sec.

5 period memory display

<table>
<thead>
<tr>
<th>Search Scale</th>
<th>Trans. Period</th>
<th>Ships Motion</th>
<th>Range Bin Size</th>
<th>5 Period Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Kyd</td>
<td>3.125 sec.</td>
<td>26 yd/period</td>
<td>52 yd</td>
<td>3 bins</td>
</tr>
<tr>
<td>5 Kyd</td>
<td>6.25 sec.</td>
<td>52 yd/period</td>
<td>104 yd</td>
<td>3 bins</td>
</tr>
<tr>
<td>10 Kyd</td>
<td>12.5 sec.</td>
<td>104 yd/period</td>
<td>208 yd</td>
<td>3 bins</td>
</tr>
<tr>
<td>20 Kyd</td>
<td>25 sec.</td>
<td>208 yd/period</td>
<td>416 yd</td>
<td>3 bins</td>
</tr>
<tr>
<td>40 Kyd</td>
<td>50 sec.</td>
<td>416 yd/period</td>
<td>832 yd</td>
<td>3 bins</td>
</tr>
</tbody>
</table>
PAIR: Uncompensated Motion-Range Scale Relations

Non-alerting modes

Dual frequency

Echo time per yd. of range = 1.25 ms

Own ship's speed = 15 kt. = $\frac{81}{3}$ yd/sec.

Five period memory display

<table>
<thead>
<tr>
<th>Search Scale</th>
<th>Track Scale</th>
<th>Trans. Period</th>
<th>Ship's Motion</th>
<th>Range Bin Size</th>
<th>5 Period Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMNI RDC</td>
<td>KYD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 Kyd 0</td>
<td>2.5 Kyd</td>
<td>3.125 sec.</td>
<td>26 yd/period</td>
<td>52 yd.</td>
<td>3 bins 2 bins</td>
</tr>
<tr>
<td>5 Kyd 0</td>
<td>2.5 Kyd</td>
<td>6.25 sec.</td>
<td>52 yd/period</td>
<td>104 yd.</td>
<td>3 bins 2 bins</td>
</tr>
<tr>
<td>5 Kyd 0</td>
<td>5 Kyd</td>
<td>6.25 sec.</td>
<td>52 yd/period</td>
<td>104 yd.</td>
<td>3 bins 2 bins</td>
</tr>
<tr>
<td>4 Kyd 10 Kyd</td>
<td>2.5 Kyd</td>
<td>25 sec.</td>
<td>208 yd/period</td>
<td>208 yd.</td>
<td>5 bins 3 bins</td>
</tr>
<tr>
<td>4 Kyd 10 Kyd</td>
<td>5 Kyd</td>
<td>25 sec.</td>
<td>208 yd/period</td>
<td>208 yd.</td>
<td>5 bins 3 bins</td>
</tr>
<tr>
<td>4 Kyd 20 Kyd</td>
<td>2.5 Kyd</td>
<td>37.5 sec.</td>
<td>312 yd/period</td>
<td>416 yd.</td>
<td>4 bins 2 bins</td>
</tr>
<tr>
<td>4 Kyd 20 Kyd</td>
<td>5 Kyd</td>
<td>37.5 sec.</td>
<td>312 yd/period</td>
<td>416 yd.</td>
<td>4 bins 2 bins</td>
</tr>
<tr>
<td>4 Kyd 20 Kyd</td>
<td>10 Kyd</td>
<td>37.5 sec.</td>
<td>312 yd/period</td>
<td>416 yd.</td>
<td>4 bins 2 bins</td>
</tr>
</tbody>
</table>
PAIR: Uncompensated Motion-Range Scale Relations

Non-alerting modes

Single Frequency

Echo time per yd. of range = 1.25 ms.

Own ship's speed = 15 kt. = \( \frac{8\frac{1}{3}}{3} \) yd/sec.

Five period memory display

<table>
<thead>
<tr>
<th>Search Scale</th>
<th>Track Scale</th>
<th>Trans. Period</th>
<th>Ship's Motion</th>
<th>Range Bin Size</th>
<th>5 Period Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Kyd</td>
<td>0</td>
<td>2.5 Kyd</td>
<td>6.25 sec.</td>
<td>52 yd/period</td>
<td>52 yd.</td>
</tr>
<tr>
<td>5 Kyd</td>
<td>0</td>
<td>5 Kyd</td>
<td>12.5 sec.</td>
<td>104 yd/period</td>
<td>104 yd.</td>
</tr>
<tr>
<td>4 Kyd</td>
<td>10 Kyd</td>
<td>2.5 Kyd</td>
<td>46.9 sec.</td>
<td>391 yd/period</td>
<td>208 yd.</td>
</tr>
<tr>
<td>4 Kyd</td>
<td>10 Kyd</td>
<td>5 Kyd</td>
<td>56.3 sec.</td>
<td>469 yd/period</td>
<td>208 yd.</td>
</tr>
<tr>
<td>4 Kyd</td>
<td>20 Kyd</td>
<td>2.5 Kyd</td>
<td>71.9 sec.</td>
<td>599 yd/period</td>
<td>416 yd.</td>
</tr>
<tr>
<td>4 Kyd</td>
<td>20 Kyd</td>
<td>5 Kyd</td>
<td>81.3 sec.</td>
<td>677 yd/period</td>
<td>416 yd.</td>
</tr>
</tbody>
</table>
\[ P_0 = \text{Ship position when echo was received} \]
\[ P_1 = \text{Ship position at time of correction} \]
\[ M = P_1 - P_0 = \text{Ship's motion over the period being considered} \]
\[ R_0 = \text{Target range when echo was received} \]
\[ R_1 = \text{Target range at time of correction} \]
\[ \theta_o = \text{Angle between ship's course and target bearing when echo was received} \]
\[ \theta_1 = \text{Angle between ship's course and target bearing at time of correction.} \]

\[ \theta_o, R_0, P_0, P_1 \text{ and } M \text{ are known} \]
\[ R_1 \text{ and } \theta_1 \text{ are to be calculated.} \]

\[ R_1 = \sqrt{R_0^2 + M^2 - 2RM \cos \theta_o} \]

\[ \theta_1 = 180^\circ - \arccos \left( \frac{R_1^2 + M^2 - R_0^2}{2RM} \right) \]

Both of the above solutions are obtained directly from the law of cosines.

The required values for \( R_1 \) and \( \theta_1 \) are derived to a close approximation when \( R_0 \gg M \) by the following equations

\[ R_1 \text{ approx. } = R_0 - M \sin(90^\circ - \theta) \]
\[ \theta_1 \text{ approx. } = \theta_o + \arctan \left( \frac{M \sin \theta}{R_1} \right) \]
CONCLUSIONS

The amount of information available on the PAIR data processing units is insufficient to form a basis for statements about feasibility or methods of implementing own ship's motion compensation for the search display. It can be surmised that certain operations may be necessary and that the times they occupy in the transmit-receive cycle may depend on computer capability.

It would be more desirable from accuracy considerations to perform the operations continuously. Continuous integration of own-ships' motion would allow calculation and updating of a correction quantity for each beam, and storage in memory for future use. Compensation would be applied to each event word as it was taken from memory to be displayed if own ship's motion since event storage or last compensation were great enough to require correction by one full range or bearing bin.

It is worth noting that it is the old data which is corrected to the position from which the next echo is expected to come, so that the display is always correct and current with respect to own ship's progress through the water.

This way of achieving compensation requires that operations be performed while the computer is already busy storing new data and producing old data from storage for display. If the false alarm rate were 20% of the possible 11,520 display positions, about 2300 words would need to be examined per write cycle lasting about 1/30 second. Probably less than 1% of these words would require correction during any one write cycle but the total time involved is considerable.
This form of display compensation should be very satisfactory. Except for the limitations of the water and detection equipment, almost all echoes from a stationary target should appear in a single range-bearing bin. The operator would see about 1/10 of all displayed events move the space of one bin during a full transmit-receive period and these changes would be distributed through the cycle, occurring one or a few at a time.

There is a comparatively idle time lasting from 30 ms to several seconds depending on the type of transmission pulse. It might be possible to accomplish the whole compensation sequence in this period when no new data is being received. Ship's motion since last pulse transmission could be used to calculate the 48 beam correction quantities, and their application to all stored event words requiring correction might be completed before pulse transmission is ended. The operator would see the whole display change practically instantaneously.

From an accuracy standpoint this method of compensation has some theoretical deficiencies. Accelerations or course changes by own ship might cause serious inaccuracies with long transmit-receive cycles since ship's motion is calculated from one transmission to the next, while the echo may be received almost a full receive period later than the calculation of correction. This time may amount to as much as 1-1/3 minutes.

Since a display simulation project is being planned; the incorporation of a study of need, feasibility and results to be expected from own ship's motion compensation on the search display may be considered for this simulation.
Target = 10,000 yd.

Target speed = 0

Ship speed = 15 kt = \(8\frac{1}{3}\) yd/sec.

Ship turn rate = \(3^o\) per second

Transmission period = 81.3 sec.

Predicted \(R_1 = 9,322.5\) yd.

True \(R_1 = 9,858.4\) yd.

Range Error = 536 yd

Bearing Error = \(3.4^o\)

1 range bin = 416 yd.

1 bearing bin = \(7\frac{1}{2}\) degrees

Total error is about \(1\frac{1}{4}\) range bins and less than \(\frac{1}{2}\) bearing bin.

For Bearing Error of \(7\frac{1}{2}^o\), \(R_o = 4619\) yd.
Ship's motion per period = 81.3 x 8\(\frac{1}{3}\) yd = 677.5 yd

Time to turn 90° at 3°/sec = 30 sec.

Distance in turn = 30 x 8\(\frac{1}{3}\) yd = 250 yd.

Distance after completion of turn = 677.5 - 250 = 427.5 yd.

Radius of turn = \(\frac{4 \times 250}{2\pi}\) = 159 yd.

\[ R_1 = \sqrt{(10,000 - 159)^2 + (159 + 427.5)^2} = 9858.4 \text{ yd}. \]

Bearing error is the difference between true bearings from P\(_1\) and P\(_1\) predicted.

\[ E_b = \arcsin \frac{159 + 427.5}{9858.4} = 3.4° \]

For bearing error = 7\(\frac{1}{2}\)°,

\[ R_o = \frac{159 + 427.5}{\tan 7.5°} + 159 = 4619 \text{ yd}. \]
\( R_0 = 10,000 \text{ yd} \)

Target speed = 0

Ship speed = 15 kt = \( 8 \frac{1}{3} \text{ yd/sec.} \)

Ship turn rate = 1° per sec.

Transmission period = 31.3 sec.

Predicted \( R_1 = 9322.5 \text{ yd} \).

True \( R_1 = 9536 \text{ yd} \).

Range error = 213.5 yd

Bearing Error = 2.4°

1 range bin = 416 yd

1 bearing bin = 7\( \frac{1}{2} \)°

Total error is about \( \frac{1}{2} \) range bin and about 1/3 bearing bin.

For Bearing Error of 7\( \frac{1}{2} \)°, \( R_0 = 3557 \text{ yd} \).
Ship's motion per period = $81.3 \times \frac{81}{3}$ yd = 677.5 yd.

Course change at $1^\circ$/sec = $81.3$ sec x $1^\circ$/sec = $81.3^\circ$

Radius of turn = $\frac{360 \times \frac{81}{3}}{2\pi} = 477$ yd.

\[
R_1 = \sqrt{(10,000 - 477 \sin 81.3^\circ)^2 + (477 - 477 \cos 81.3^\circ)^2}
\]

$R_1 = 9536$ yd

Bearing Error

\[E_b = \arcsin \frac{477 - 477 \cos 81.3^\circ}{9536} = 2.4^\circ\]

For Bearing Error = $7\frac{1}{2}^\circ$,

\[R_2 = \frac{477 - 477 \cos 81.3^\circ}{\tan 7.5^\circ} + 477 = 3557 \text{ yd.}\]