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Analysis of Remote Minehunting System Vehicle Sensor and Sonar Data Reveals System Problems

Anna Crawford

David Hopkin

Defence R&D Canada – Atlantic

Technical Memorandum

DRDC Atlantic TM 2004-256

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Abstract

Processing and analysis of the bathymetry and sidescan data collected during the most recent Remote Minehunting System (RMS) trial in Esquimalt, spring of 2004, together with examination of the vehicle sensor logs have revealed several potentially serious system problems. This informal document lists these so that effort can be directed to ensure that similar issues are avoided during subsequent trials.

Résumé

Le traitement et l'analyse de données de sonars bathymétriques et à balayage latéral recueillies lors de l'essai le plus récent du systéme télécommandé de chasse aux mines (RMS) à Esquimalt, au printemps de 2004, conjointement avec l'examen des données de capteurs de véhicule, ont révélé plusieurs problèmes qui pourraient être graves. Le présent document, de nature informelle, énumère ces problèmes en vue de permettre d'orienter les efforts de recherche de manière à éviter que de tels problèmes se présentent lors des essais ultérieurs.

Executive summary

Introduction

Through its development, the Remote Minehunting System (RMS) has been field tested in a series of demanding sea trials. The most recent of these was in Esquimalt during the spring of 2004.

Significance of Results

Analysis of the sonar data (sidescan and bathymetry) and vehicle sensor data that was recorded during the trial shows that there are some problems with the system. Some are not considered to be serious, like the inverted output of the heave sensor, while others such as the low sidescan sonar signal level are quite grave.

This informal report documents some issues that have been identified, with illustrative samples from the recorded data, so that RMS performance can be improved.

Future

From this point forward in the evolution of the RMS, trials should become more oriented toward scientific goals using the system as a tool rather than toward testing of the system itself.

Crawford, Anna M. 2004. Analysis of Remote Minehunting System Vehicle Sensor and Sonar Data Reveals System Problems. DRDC Atlantic TM 2004–256. Defense R&D Canada – Atlantic.

Sommaire

Introduction

Tout au long de son développement, le système télécommandé de chasse aux mines (RMS) a fait l'objet d'essais en mer rigoureux. Le plus récent a eu lieu à Esquimalt au printemps de 2004.

Portée des résultats

L'analyse des données de sonar (à balayage latéral et bathymétrique) et des données de capteurs de véhicule recueillies lors de l'essai indique un certain nombre de problèmes liés au système. Certains ne sont pas jugés graves, p. ex. la sortie inversée du détecteur de pilonnement, mais d'autres, comme le faible niveau du signal du sonar à balayage latéral, sont très graves.

Le présent rapport, de nature informelle, documente certains problèmes qui ont été identifiés, en présentant des exemples tirés des données recueillis, afin de permettre l'amélioration des performances du RMS.

Recherches futures

L'évolution du RMS devrait dorénavant viser davantage l'utilisation du système comme outil, en fonction d'objectifs scientifiques, plutôt que sa mise à l'essai.

Crawford, Anna M. 2004. Analysis of Remote Minehunting System Vehicle Sensor and Sonar Data Reveals System Problems. DRDC Atlantic TM 2004–256. Defense R&D Canada – Atlantic.

Table of contents

List of figures

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1 Introduction

Processing and analysis of the bathymetry and sidescan data collected during the most recent Remote Minehunting System (RMS) trial, referred to as Victoria 2004 here, together with examination of the vehicle logs, have revealed several potentially serious system problems. This informal document lists these so that effort can be directed to ensure that similar issues are avoided during subsequent trials.

The outputs of the navigation and attitude sensors onboard the Dorado vehicle and sonar towfish are logged in a series of time–stamped vehicle logs. Some sensors are redundant, so comparisons can be made between measurements which should be in agreement. Performance of the RMS in route following and seabed target positioning can be improved by identifying and correcting system weaknesses such as those found in this study.

The document is organized in sections titled “Ancillary Sensors”, covering aiding sensors such as the vehicle Inertial Navigation Unit (INU) and Global Positioning System (GPS) receiver, “Sidescan Sonar”, which covers the Klein 5500 sonar, and “Bathymetric Sonar”, which covers the Reson 8125 sonar.

2 Ancillary sensors

This section includes discussion of problems found with the Octans INU (heave and heading), GPS receiver, time synchronization, and altimeters.

2.1 Octans Heave and Heading

Just prior to the Victoria 2004 trial, the Octans gyrocompass/motion sensor on the Dorado was upgraded. When the new unit was installed, the heave output was inadvertently set to the opposite sign than in the previous installation. This was discovered when processing the bathymetry data after the trial.

A 20 cm trough–to–peak measured heave oscillation, by virtue of the incorrect sign, corresponds to a 40 cm artifact in the processed bathymetry measurements. This has been corrected by exporting the heave time series from the processing software (CARIS HIPS) and reinserting into each data file individually using another software utility (the so–called Generic Data Parser) with a sign change.

It appears that the heading output by the Octans was unreliable during the trial. Over periods of about 45 minutes to an hour, the Octans heading output gradually wandered off by +/-10–20° then returned. This happened several times during the trial, no more than once a day, starting at seemingly random times, regardless of whether compass calibration exercises (a series of long legs at constant headings) were performed or not. Octans heading in the 10 Hz ”fast” vehicle logs can be compared to another log field “vcc_compass_fb_deg” (though I am unsure of the source of this information), and to towfish heading when the towfish INU (PHINS) was functioning properly, keeping in mind that the towfish follows the vehicle on its own track. Figure 1 shows a typical example from May 7. Figure 2 shows the vehicle track during this time period overlayed with two sets of instantaneous heading arrows: the Octans heading is shown in red and the “compass” heading is in black.

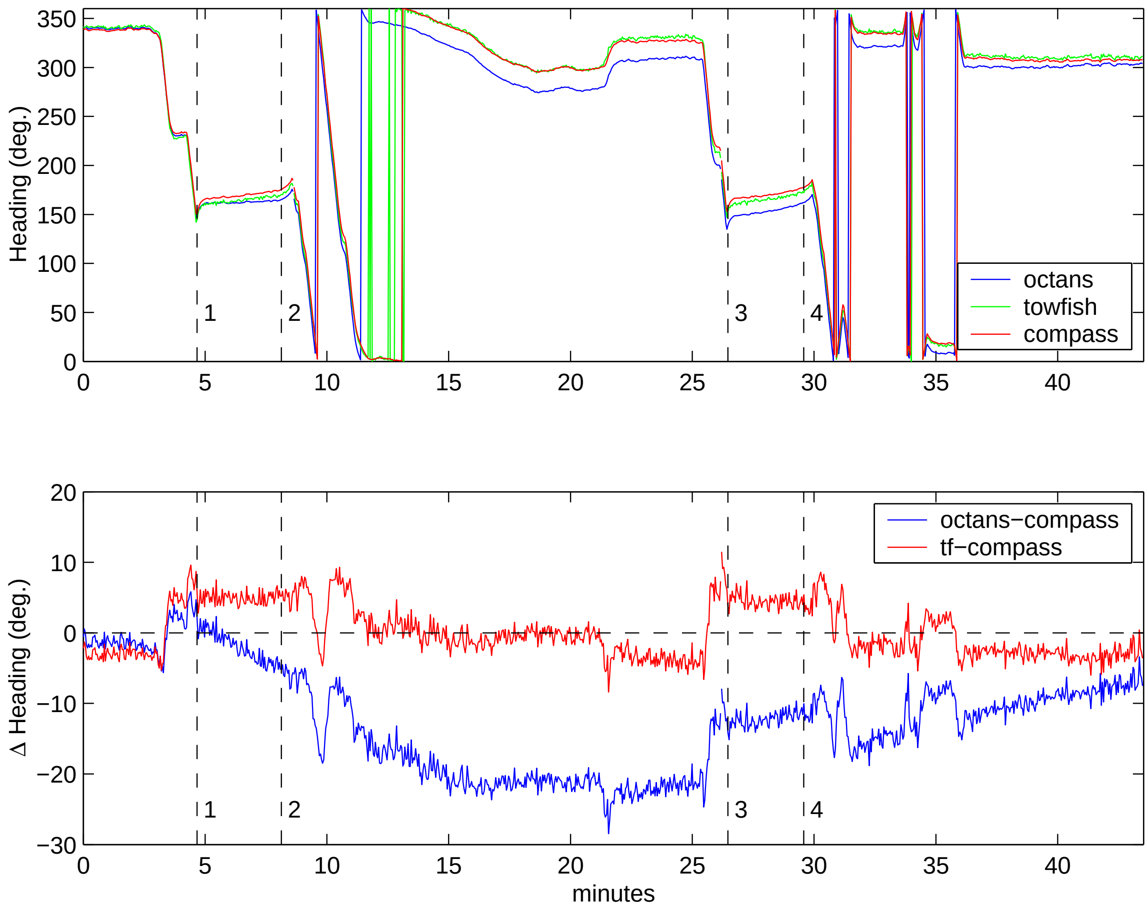

Figure 1: *Time series of heading measurements showing Octans (blue), PHINS towfish (green) and "compass" (red) heading outputs over a 45 minute period in the upper plot. The lower plot shows the difference between Octans and "compass" (blue) and between towfish and "compass" (red) headings over the same time period. Numbered vertical lines show approximate start and stop times of bathymetric survey lines.*

Over the 45 minute period shown, the difference between Octans and "compass" heading increases to about 20°, then returns to small values. In the plan view plot, the black arrows ("compass") generally agree with the course of the vehicle, while the Octans heading is slewed to port.

Two bathymetric survey lines were run during this time period, between the labels "1" and "2" and between "3" and "4". Octans heading was input directly to the Reson processor and hence into the recorded bathymetry data files. Usually it so happened that the Octans heading was in line with what it should be during bathymetric measurements. The data files containing bad heading data were repaired by importing a course–made–good using the CARIS Generic Data Parser. Note that the "vcc_dgps_course_true_fb_deg" vehicle log data during this trial was also quite unreliable, showing long periods of essentially noise.

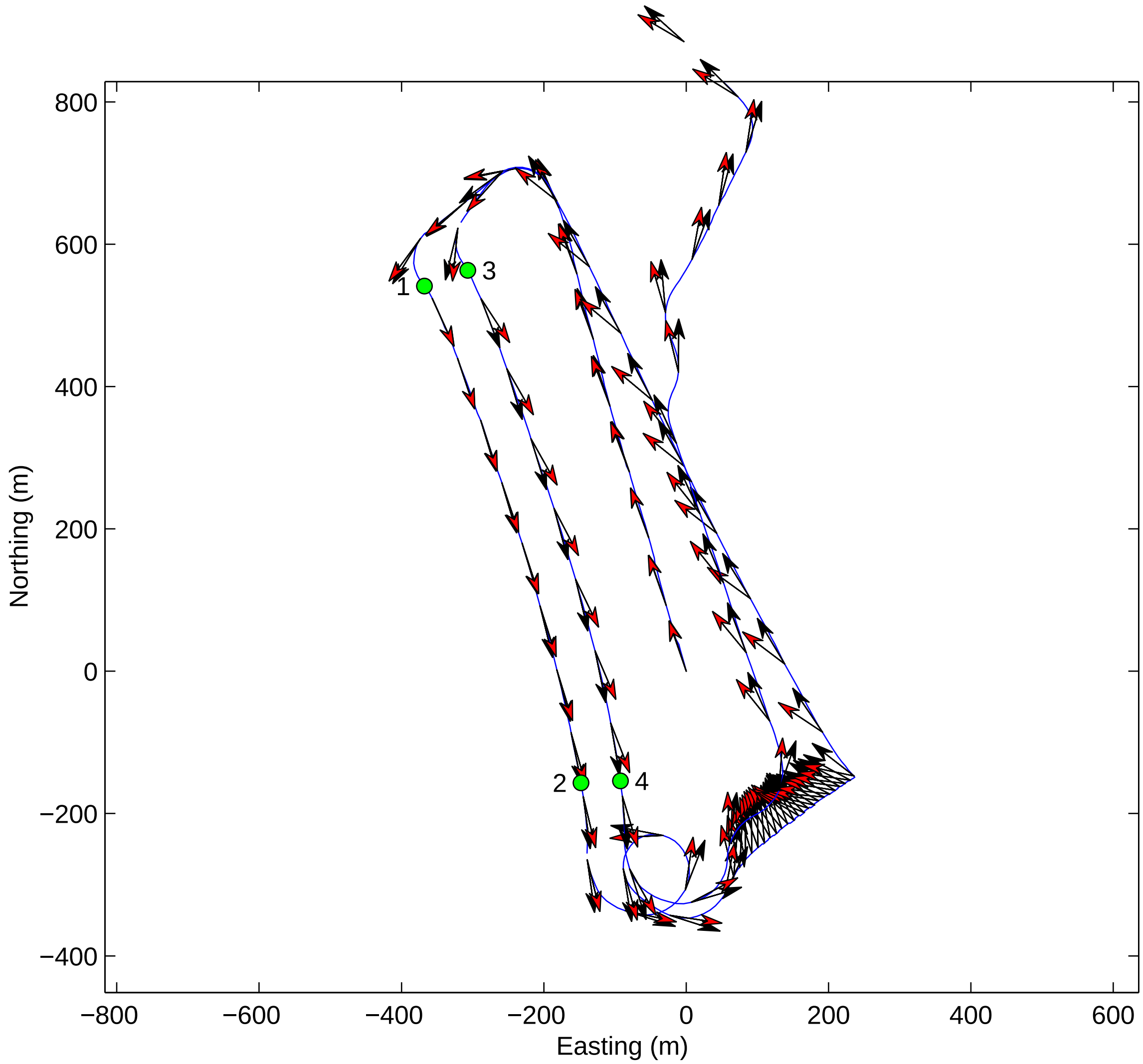

Figure 2: *Plan view of vehicle track associated with the time series shown in the previous Figure with instantaneous heading indicated by the arrows: red arrows are Octans and black are "compass". The labelled green dots correspond to the numbered vertical dashed lines in the previous Figure.*

2.2 GPS

During the Victoria 2004 trial, the quality of the vehicle positioning provided by the Dorado onboard Differential GPS system was poor. The same system (Racal Landstar Mk4) has been used on previous trials in Esquimalt and Brest, France.

Figure 3 shows sample "fast" and "slow" (1 Hz) vehicle log data summarizing typical DGPS positioning performance during the trial. The upper plot shows the reported age of the current differential correction in seconds. The dashed horizontal line indicates an age of 30 s and anything older is given a value of 99 s. The middle plot shows the heading between consecutive vehicle positions

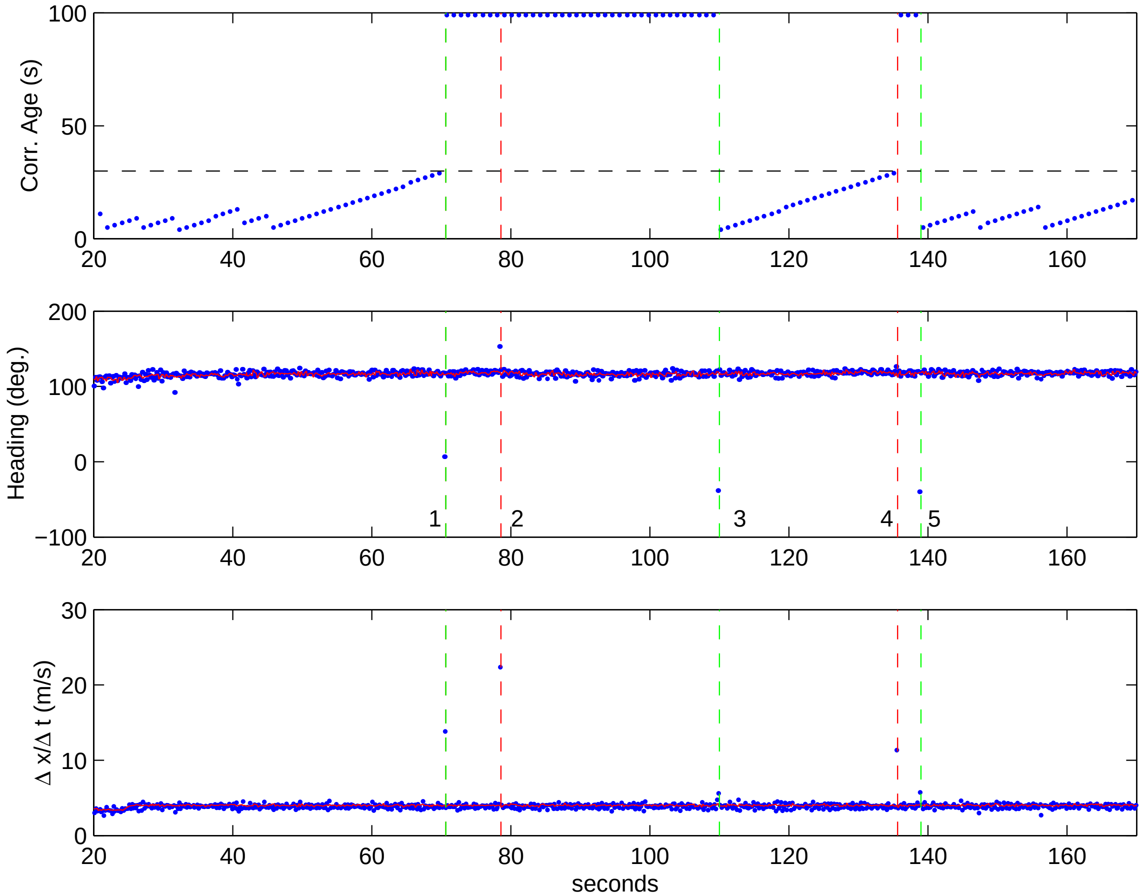

Figure 3: *Time series of GPS parameters: age of the differential correction (top), position–to–position heading (middle), and position–to–position distance over time (bottom). Vertical dashed lines and numbers label "jumps" in position, characterized by discontinuities in heading or displacement.*

(blue dots, $\arctan(\Delta x/\Delta y)$ with x and y in UTM Easting, Northing coordinates) along with the vehicle heading reported by the Racal (red line). The bottom plot shows the distance travelled between positions divided by the time elapsed (blue dots) and the vehicle speed reported by the Racal (red line). The update rate of the Racal (about 2 Hz) is about half the sample rate of the fast vehicle logs, so duplicate positions returning nonsense heading and zero Δx values have been removed and accounted for in the calculations. The vertical dashed lines with number labels indicate times where the vehicle track "jumps" with discontinuities in either heading or distance travelled, or both. Figure 4 illustrates in plan view the associated track of the vehicle during this time period, with the 5 jumps shown in Figure 3 magnified in the insets.

The jumps most often coincide with either the $>$30–s–old expiry or reacquisition of differential corrections — it seems like the Racal does not use differential corrections older than 30 s and switches to an uncorrected mode. The frequency of update of the differential corrections as either supplied by the Landstar network or successfully received by the Racal unit (not clear which), is

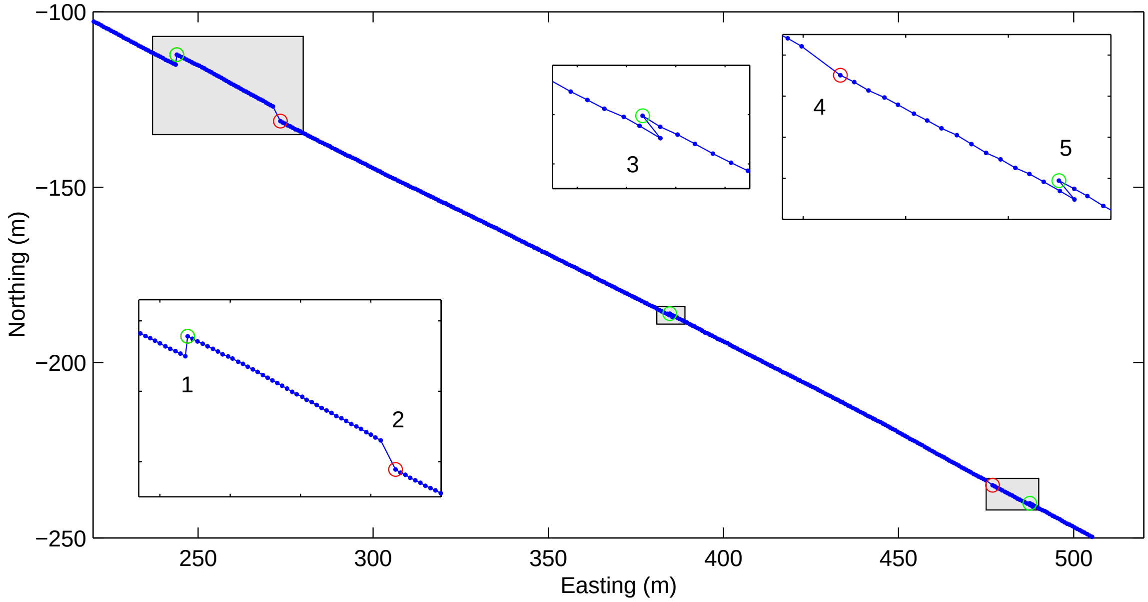

Figure 4: *Plan view of vehicle track associated with the time series shown in the previous Figure. The insets magnify the labelled jumps in position.*

almost always far less often than at 5 second expected intervals.

When looking online for specifications for the Racal Landstar Mk4, I learned that the branch of Racal dealing with the Landstar network was successively morphed into Thales (sometime in 2000), then purchased by Fugro–Omnistar (Nov. 2003). The Landstar (a.k.a. Thales' Skyfix) network has been superseded by Fugro's Omnistar network. Fugro has said it will continue to provide service to Racal Landstar subscribers, but receivers will probably need to switch frequencies and update access codes (see the notice from Fugro to Landstar customers posted on Dec 3, 2003 at http://www.omnistar.nl/news/2003/20031203.asp). Presumably this was taken care of, or no differential corrections would have been supplied, as was unfortunately the case during the earlier RMS Build trials.

Qualitative comparison between vehicle tracks recorded off Esquimalt during Build 3 (no differential correction) and during the Victoria 2004 trial show the Landstar differential correction gives no great improvement, in the sense that there are as frequent or even more jumps occurring as the Racal switches in and out of differential mode every few minutes. These jumps skip about the same horizontal distance as the jumps commonly seen in regular uncorrected GPS mode. Andrew Westwell-Roper notes in the Build 3 Trials Report that during Build 3 there was a 10 m north–south offset between shore–station–supplied differential correction (GIBS) positions and the vehicle uncorrected GPS positions — presumably long term bulk positioning offsets like this should be eliminated by the differential correction. On the shorter term, offsets of the vehicle track such as between labels 1 and 2 in Figure 4 could contribute to positioning error.

2.3 Timing Issues

There is a puzzling time synchronization mismatch between the fast and towfish_fast vehicle logs and between the logs and the sidescan sonar data files. Comparing log entries common to both sets of logs (tcc_phins... entries in the towfish_fast logs with tcc_pos... entries in the fast logs, while PHINS position was being filled in for towfish position, for example), the towfish_fast logs lead the fast logs by usually about 1.5 s, though sometimes up to 2 s or as little as 0.6 s. During the trial in Brest, the towfish_fast logs led the fast logs, but only by 1/3 to 1/2 a second. The sonar data files lead the vehicle logs by variable amounts depending on whether the sonar data was logged by RMS systems (by about 1/2 a second) or directly onto a laptop in the vehicle bay (within the sampling interval of the fast logs, 1/10 s).

While processing the bathymetric data it became evident that there was a 1/3 s latency in the position information being written to the Reson data files. It is not clear where this delay is being introduced, since in theory, the Reson system uses GPS pulse–per–second inputs for synchronization of the various data streams coming into the processor.

Another interesting time synchronization problem occurred on May 10. A truncated fast vehicle log ends with the time stamp 23:18:15, and the next one containing any contents starts with 23:12:24 (there are several empty ones between). The towfish_fast logs appear to be continuous with no discontinuity. Correlation of like records in the towfish_fast and fast logs shows the fast logs lag by 00:16:28.5 after the gap. This persists for the remainder of the mission. The system restarts normally the next morning. My personal log doesn't mention this event, but I think this coincides with a hard power–down and reboot of the vehicle that was performed from a RHIB during operations that day.

2.4 Altimetry

Figure 5 shows an example of altitude measured by the Doppler Velocity Log (DVL), by the Klein altimeter, and derived from the sidescan sonar data itself. Over a flat seabed and while the towfish is travelling without significant roll or pitch accelerations, the DVL performs well as an altimeter, but otherwise underestimates the distance to the seabed. RDI claims 1% accuracy in range to bottom measurements by the Workhorse Navigator 300 DVL (http://www.dvlnav.com/the_facts.html). The Klein altimeter is unreliable apparently due to low signal level with frequent dropouts, though it is performing normally in the sample of data shown here — it usually over–estimates altitude slightly, and lags sudden changes due to filtering of the output. Algorithms that were developed for deriving altitude from the first return in the sidescan sonar data itself are not reliable when applied to the RMS data also due to the low signal level (see discussion in the following section).

The inaccuracies in towfish altitude measurement are small ($<3\%$), so they do not affect either terrain–following or sidescan data georeferencing greatly.

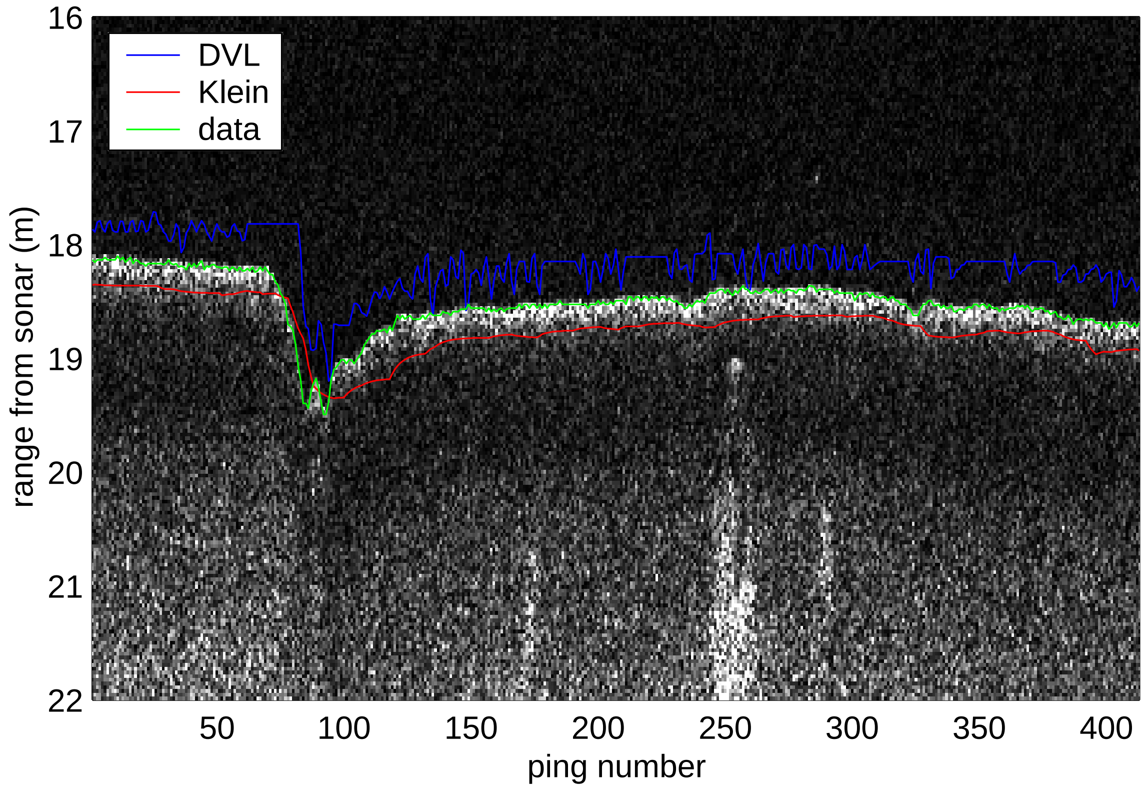

Figure 5: *Comparison of altitude measurements by DVL (blue), Klein altimeter (red) and derived from the sonar data (green), overlayed on scaled raw sonar data.*

3 Sidescan Sonar

This section includes discussion of problems encountered with the Klein 5500 sidescan sonar data. This consists of a single issue: the received signal level.

3.1 Signal Level

The signal level in the Klein sonar data has been a concern since RMS Build 2. During Build 2, signal levels were quite low and it was recommended to increase the Klein receiver Time Variable Gain (TVG) setting. The dynamic range of sidescan sonar data directly impacts the performance of the automated target detection algorithms that work on either image contrast (between highlight, shadow, and/or surrounding seabed) or on statistical properties of the sonar image data. The Klein receiver has 12–bit range (0 to 4095 counts), though it is normal for recorded sonar data to only very rarely exceed half that in the brightest highlights. As the quality of the sidescan sonar data is of critical importance to a minehunting system, it is beneficial to revisit this issue.

Comparison between examples of sonar data from different deployments is difficult as the signal level depends very strongly on the local seabed characteristics, and in particular, there is no geographic area that has been surveyed with DRDC's Klein sonar both stand–alone ("pre–RMS") and integrated into the RMS. Figure 6 demonstrates a wide range of averaged received levels over several deployments. Each curve represents the ensemble average of several thousand beamformed pings from a particular survey (both port and starboard sides together) while the sonar was travelling at relatively constant altitude, though at a different altitude in each case. The three examples from pre–RMS deployments were collected at three different locations near Halifax during the MAPLE2001 joint Canada–NURC experiment. The Build 2, Build 3 (both in 2002) and Victoria 2004 data were recorded over the same area of seabed, transiting the entrance to Esquimalt Harbour. The Brest and GESMA examples were recorded over the same area in Brest Harbour in 2004 during a joint Canada–France trial, however the GESMA sample was recorded by the French with their Klein 5500 modified for interferometric bathymetry. The samples of data in Figure 6 are listed in the legend chronologically and in each case, the transmit pulse setting is indicated as 0 (all transducer elements) or 8 (the end elements disabled, giving a 33% shorter array and less transmitted acoustic energy) and the TVG setting as 7 (the default) or 8 (3 dB higher). DRDC's Klein sonar was modified after Build 3 to also record raw data from the individual staves in the array, though it is the beamformed data that is shown in all cases. Only one case, one of the Victoria 2004 examples, was recorded while collecting the raw stave data. The GESMA Klein was operating in a mode where interferometric bathymetry data was recorded, but not stave data, though it also has that capability.

Another way of looking at the same information is as distributions of signal level, shown in Figure 7. To minimize the effect of the different sonar altitudes and noise contributions, only samples 800 to 2000 in each ping (approximately 25 to 65 m range, between the red dashed lines in Figure 6) have been counted. The distributions have been normalized by the number of pings, so the integrated area under each curve equals the number of samples used from a ping (1200).

Another complication in comparing signal levels is that before integration into the RMS, the sonar was often operated with a "despeckling" filter enabled, as was the case during MAPLE2001. For a more accurate comparison with the pre–RMS data, the RMS Klein data has been despeckled using

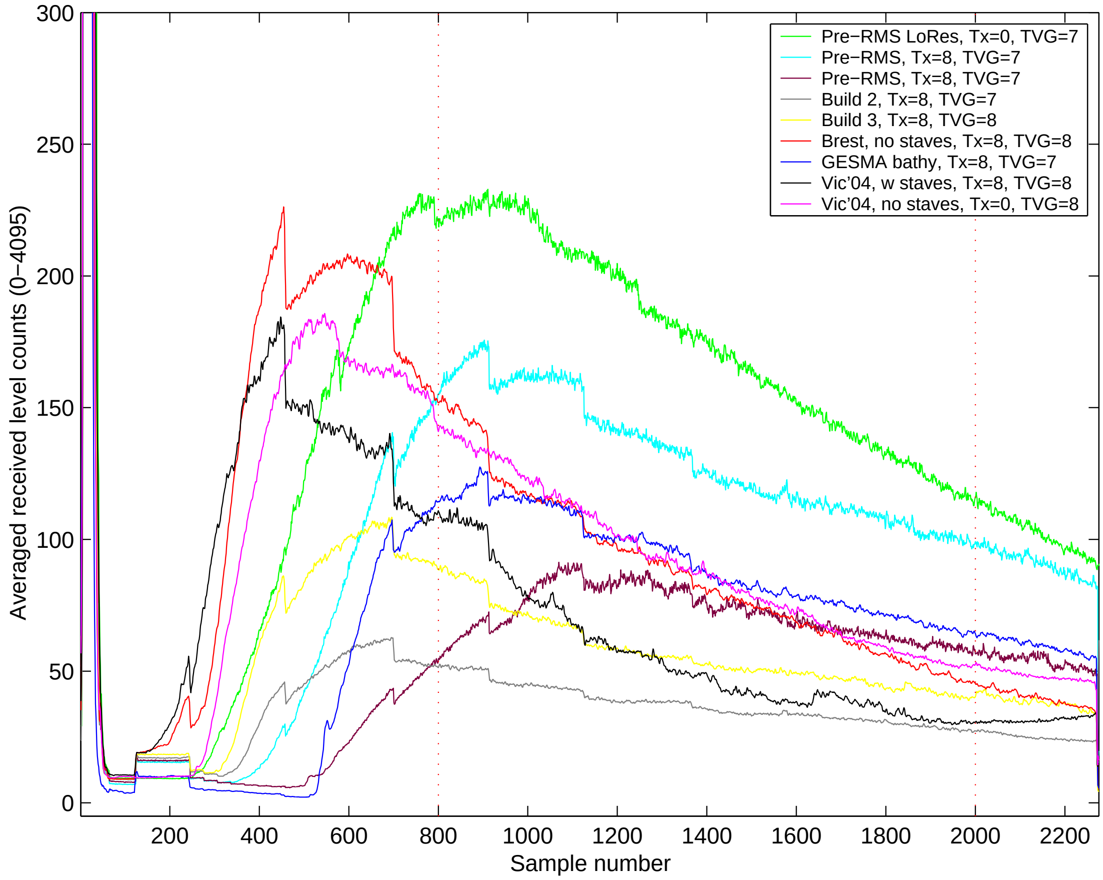

Figure 6: *Comparison of averaged signal levels from several Klein deployments. Several thousand port and starboard pings are averaged in each case. Deployments are in chronological order in the legend, with the transmit pulse (Tx) and TVG settings indicated for each.*

an along–ping 3–sample boxcar filter, emulating a Klein despeckle filter setting of 1. The effect of the filter can be seen in Figure 8, which shows the distributions of the Victoria 2004 data recorded without the stave data, filtered and unfiltered, along with fitted theoretical distributions. The low end of the despeckled distribution is greatly reduced and the peak increased and shifted slightly toward higher signal level. The effect on ensemble averaged ping data like that shown in Figure 6 is negligible. The unfiltered data is well matched to a K–distribution, also shown in Figure 8, while the filtered data has closer to a Rayleigh distribution. Seabed classification schemes operating on the statistics of the seabed backscatter would likely be affected by the despeckle filter, hence its discontinued use.

Several conclusions can be drawn from the complicated plots shown in Figures 6 and 7. The three examples of pre-RMS data illustrate the wide range of received signal levels over varying seabed types, with the lowest levels from a site in Herring Cove (listed third in the legend) falling below most of the others, including some of the RMS data. The lowest averaged levels shown are from the Build 2 deployment when this issue was raised as a concern. In the representative examples shown

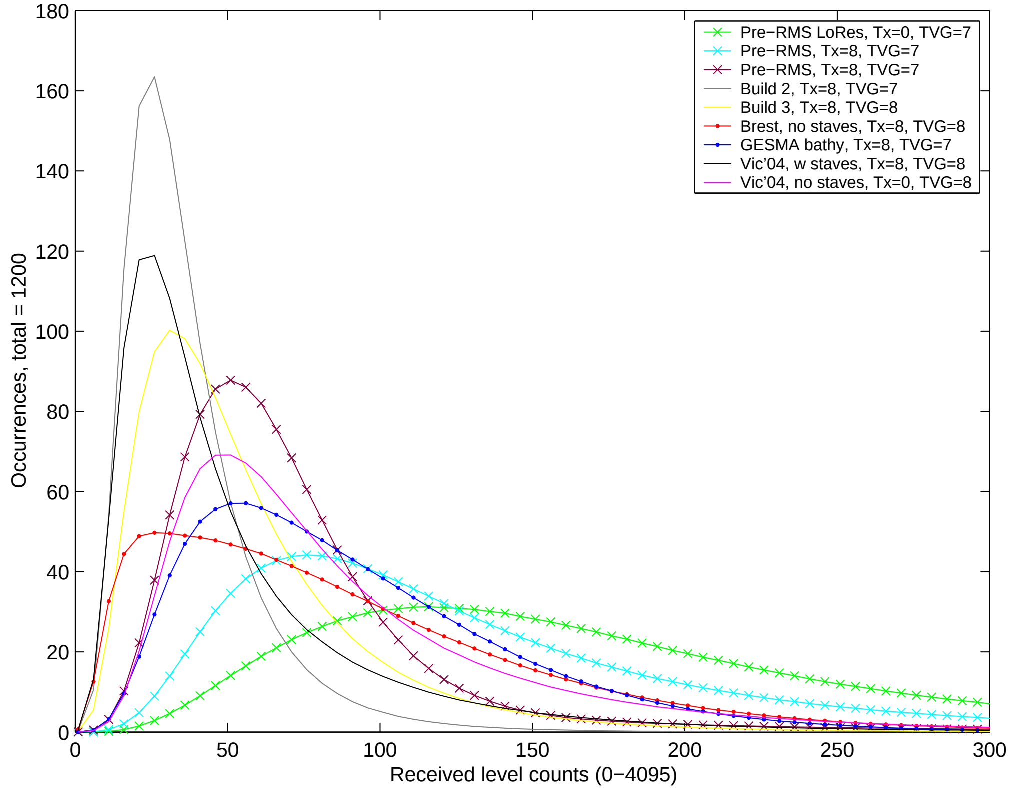

Figure 7: *Comparison of signal level distributions from several Klein deployments. The RMS Klein data has been "despeckled" for comparison with the pre–RMS data.*

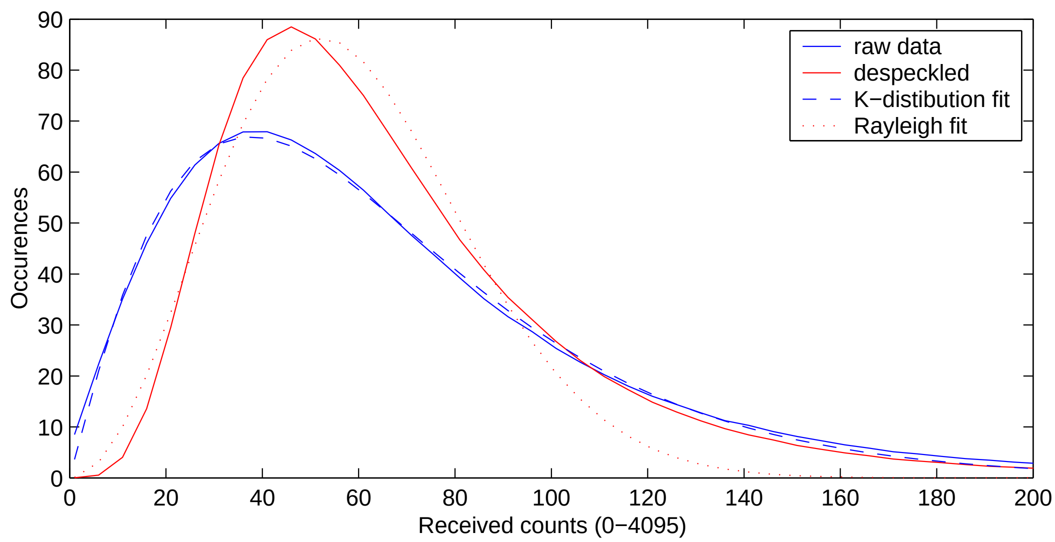

Figure 8: *Effect of despeckle filtering on signal level distribution.*

here, the level increased for the Build 3 deployment (increased TVG setting), and again for the Victoria 2004 trial (while not recording the stave data, the full transmit array was used). Comparing the two Victoria 2004 trial examples, there is a significant decrease in signal level in the beamformed data while logging the raw stave data, which may be due to the decreased transmit array or some change in the Klein on–board signal processing when operating in this mode. The peaks of the distributions for the pre–RMS data are at higher levels than the RMS data, though not by much in the case of the Herring Cove data. The high end tails of the distributions show an increase in the same progression as the averaged levels from Build 2 through to the Victoria 2004 trial. Comparing DRDC's Klein with the GESMA Klein, the distribution peaks at lower signal level, even though the TVG setting is higher, however it is perhaps dangerous to compare two sonars which have both had significant post–factory modifications. The Aurora towfish, into which the Klein is integrated as part of the RMS, was completely rebuilt between the trial in Brest Harbour and the Victoria 2004 trial. The distribution for the Victoria 2004 trial (without stave data) peaks at the highest signal level of all the examples of RMS Klein data, spreads wider into higher signal levels, and more closely resembles the distribution of pre–RMS and GESMA (stand–alone) Klein signal levels.

To summarize this discussion, the signal level has been much improved since it was noted as being low in Build 2, by increasing the TVG setting and using the full array transmit pulse. Increasing the TVG setting is a less than optimal solution, however, since this amplifies signal and noise indiscriminately. As well, using the full transmit array is not ideal when operating the sonar in high resolution mode. Though still appearing to have lower averaged levels than in the pre–RMS deployments, the signal level distribution now resembles pre–RMS distributions more closely since the rebuild of the Aurora prior to the most recent trial. Further dedicated testing would be required to determine this absolutely, such as a pair of surveys of a well characterized area with the Klein by itself and as part of the RMS.

4 Reson Sonar

This section includes discussion of problems encountered with the Reson 8125 bathymetric sonar data. The Octans heading and heave problems discussed earlier also affected the bathymetric data collected during the trial.

4.1 Ping Rate/Survey Speed

In order not to overload the radio communication channel between the Dorado and support vessel, the Reson ping rate was kept at a bare minimum, even though the data link was probably capable. At times, this meant that at the customary Dorado survey speed of 6–8 knots, the coverage of the resulting bathymetric survey data was not up to requirements. For example, several passes over the '88 Array yielded bathymetry data with too coarse resolution to resolve the targets clearly since soundings from consecutive pings were separated by 1–1.5 m on the seabed. Figure 9 shows a sample of this data. The sounding density is only barely adequate to resolve the large scour holes surrounding the targets. At that location with 50 m water depth, the maximum ping rate of the Reson is about 5 Hz and at that time, it was set at 3 Hz. In theory, with perfect positioning, repeat overlapping passes should fill in the gaps, however in practice, this is hit–or–miss (see the discussion on GPS positioning). It is better to survey at a slower speed with the maximum ping rate allowed by the water depth.

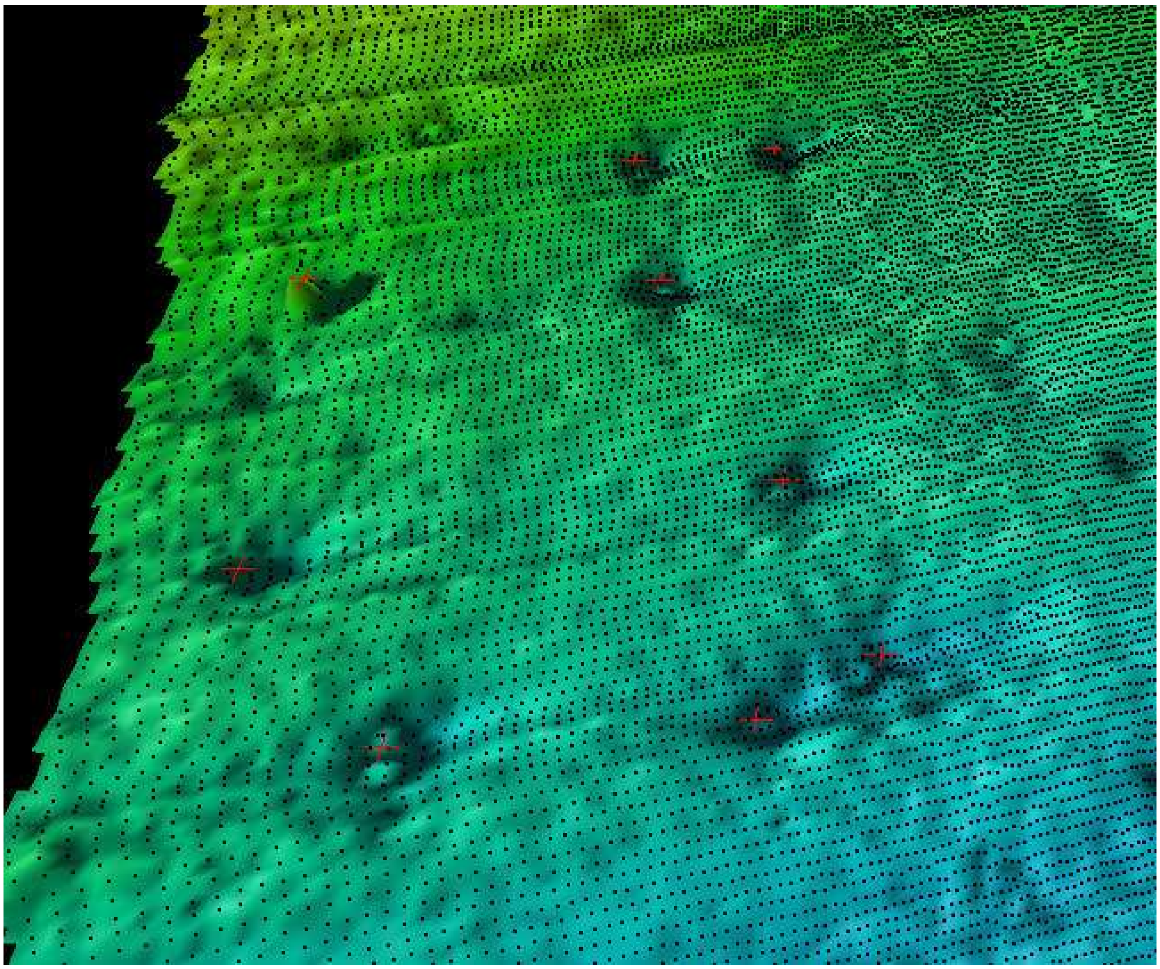

Figure 9: *Sample of processed bathymetric survey data (1 m grid spacing) over the ’88 Array, with the individual soundings shown as black dots. The view angle is oblique from a 45 degree elevation, looking northward. Some of the array target locations are marked with red + symbols.*

4.2 Sound Speed

The presence of refraction errors in the bathymetry data seems to indicate that the sound speed input to the Reson processor (used for beamforming) is inaccurate. The CARIS HIPS processing software allows refraction corrections to be applied and though these were generally no more than a few meters per second in sound velocity, this can correspond to up to a 1/2 m vertical deviation in the seabed elevations at the outer beams. Local measurements of the sound speed profile were made at the time of some of the bathymetric surveys, and these were used in processing the bathymetry data. Incorrect sound speed input to the Reson processor is evident in what appear to be compound refraction errors not correctable by adjusting the sound speed profile used in the post–processing. Some refraction error is unavoidable when operating in an area such as the Esquimalt Harbour approaches where there are strong tidal currents and river outflow.

The dedicated sound speed probe for the Reson processor (a time–of–flight instrument) is located behind a perforated cowling inside a cavity in the vehicle body, forward of the winch housing. Perhaps this cavity is not flushed rapidly or well enough to give an accurate local sound speed measurement.

5 Summary and Recommendations

In order of decreasing gravity, I would rate the Klein low signal level as the most serious issue, followed by the timing inconsistencies. Low signal level degrades sidescan sonar data quality, which should be a primary concern. It is not possible to quantify this definitively however, mainly because the same area has never been surveyed both with the Klein sonar by itself and integrated into the RMS. A timing discrepancy of 1 s at a routine survey speed of 8 knots translates into a horizontal positioning offset of 4 m – this is a large fraction of the RMS target positioning accuracy specification (10 m root–mean–squared).

The problem with the quality of the DGPS positioning can be solved by switching to a new or better GPS receiver. For trials in regular operating areas, shore–based differential corrections can be used for free. The Octans heading and heave problems are matters of instrument settings and tuning the system. The Reson ping rate vs. survey speed problem is a matter of operational experience. The underestimation of altitude by the DVL may perhaps be considered as a safety margin when operating in terrain–following mode and only affects georeferencing of the sidescan data significantly in the near–nadir area. The Reson sound speed probe can perhaps be moved to sample external to the vehicle hull, though it needs to be in a location where flow will not carry significant numbers of bubbles through the sample volume.

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(U) Processing and analysis of the bathymetry and sidescan data collected during the most recent Remote Minehunting System (RMS) trial in Esquimalt, spring of 2004, together with examination of the vehicle sensor logs have revealed several potentially serious system problems. This informal document lists these so that effort can be directed to ensure that similar issues are avoided during subsequent trials.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

Remote Minehunting System

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