TELEMETRY IN TESTING OF UNDERSEAS WEAPONS

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ABSTRACT

The performance testing of underseas weapons involves many of the same challenges as for other “smart” systems. Data sets on the order of GigaBytes must be extracted, processed, analyzed, and stored. A few KiloBytes of significant information must be efficiently identified and accessed for analysis out of the great mass of data. Data from various sources must be time correlated and fused together to allow full analysis of the complex interactions which lead to a given test result. The fact that the various sources all use different formats and medias just adds to the fun.

Testing of underseas weapons also involves some unique problems. Since real time data transmission is not practical; the vast bulk of the test data is recorded and then recovered with the vehicle at the end of the test. Acoustics are relied on for identification and ranging.

As systems continue to get smarter; the rates, capacities, and “smarts” of the equipment and software used to process test data must similarly increase. The NUWES telemetry capabilities developed to test and analyze underseas weapons could be of use on other government related projects.

“Key words: Telemetry, data processing, data analysis, undersea weapons, smart weapons, torpedoes, performance testing.”

INTRODUCTION

Before the attack on Pearl Harbor, the Mark XIV Torpedo was considered one of the most lethal weapons in the history of naval warfare. It had two exploders. One was a very secret “magnetic exploder”. It was backed up with a contact exploder. Unfortunately, the torpedo had a tendency to run about 10 feet too deep which kept either exploder from doing its job. This was finally established 6 months and 800 warshots later when a group of submariners decided to conduct their own test. However after some more combat, it was found that the magnetic exploder did not reliably perform even if the torpedo approached the enemy ship at the proper depth. It had a tendency to explode prematurely. And finally, after the depth was compensated for and the magnetic exploders were deactivated, it was discovered that the contact exploders were faulty. It took 21 months of warfare before all the problems with the torpedo were corrected. As you can imagine, it is rather disconcerting for a submariner to shoot a dud torpedo at an enemy ship. Particularly when the bubble trail from the torpedo marks the spot, and you are the spot.

One of the missions of the Naval Undersea Warfare Engineering Station (NUWES) at Keyport Washington, is the performance testing and evaluation of undersea weapons during development and production. The point of testing is to confirm that the weapon will actually perform as intended or more importantly what specifically will prevent it from successful performance. You cannot always depend on having developed a Patriot missile that works fine the first time. Torpedoes these days, just like other "smart" weapons; are designed to seek out, lock on; and then pursue their targets until interception. A vast amount of data is required to monitor the complex functions the weapon must perform to accomplish its mission.

TYPICAL DATA PROCESSING AND ANALYSIS

For example, the Mark 48 Advanced Capability (ADCAP) Torpedo, records on the order of 1.2 GigaBytes of data on an internal, 14 track, analog tape. Approximately 3,000 variables are distributed across 6 independent data streams. Each data stream is recorded over 1 to 4 of the 14 tape tracks. Each tape track is Pulse Code Modulated (PCM) encoded in Pseudo Random NRZ-L code at 1.25 MegaBits per second. The tape is recovered along with the torpedo at the end of the test.

To process the tape, the analog signals from each track of the tape must first be filtered, bit synchronized, and then derandomized. The reproduced bit stream is then collected into words. This portion of the process is referred to as decommutation. Word frames are formed directly after decommutation for data streams which were originally recorded over only one tape track in the torpedo. For data streams which were recorded over multiple tracks, the decommutated words from those tracks are first multiplexed back together again before frame formation. Synchronization words are embedded in the data by the torpedo to support collection of the words into frames which are fixed length per type of data stream. The next step in the process is to feed the framed data to a computer. The computer supplements each frame of data, regardless of type of data being processed, with a series of header words. These header words signify the approximate test time when the data of the frame was recorded by the torpedo.

This time tagging is accomplished as follows: One of the single track data streams includes the values from the torpedo's run clock. The computer always extracts and stores the current value of the clock from each frame of this data stream. The computer then assigns each frame of data being concurrently processed with header words encoding the current value of the clock. It is assumed that data from approximately the same position along the tape, which will result in concurrent processing by the computer, should have been sampled at approximately the same time. However, only a limited number of tracks of data may be concurrently processed due to throughput limitations. Thus the data stream containing the timing variable is processed multiple times so that it can supply clock values to all other data frames. After time tagging, the computer writes each data stream to 9 track digital tape. The 9 track tapes can be directly read by other computers during the subsequent analysis process. The described process of converting Mark 48 ADCAP recorded data to parallel digital form was developed in the early 1980s by Hughes Aircraft Corporation in conjunction with DECOM Systems Incorporated (DSI). A data flow diagram of the system assembled by DSI is shown in Figure (1).

NUWES actually uses various data extraction and preprocessing procedures. Modern technology within certain capacity and performance boundaries, has provided a wealth of various media and techniques for the recording of data. There always seems to be several systems available which can do the same job. There is also some compulsive force of nature that makes system developers choose a different recording media for each project or independent source within a project. And the odds are pretty good that the extraction and preprocessing system will also be fundamentally different from anything previous. One result of handling data from multiple projects is a diverse collection (or zoo) of front end equipment with the common characteristics of being mutually incompatible and totally useless on any future job.

The technique for time tagging data from the Mark 48 ADCAP, discussed above, is relatively straight forward and reliable. However, problems may be encountered in accurately time tagging the data from other sources. Common problems in time tagging include unreliable or non-existent clocks for a given source. Reliance is then typically placed on some sort of periodic pulse which is recorded with the data. These pulses may come from the range or other source. However, the pulses are usually widely spaced in relation to the data; and accurate time tagging may be further exasperated by a non-constant recording speed in between pulses. In any case, time tagging data can turn into quite a computational chore which often leads to the entire data set having to be reprocessed solely to add time tags.

A common challenge in analyzing test data is just how to handle the great mass of data available. Particularly when only a few KiloBytes here and there are of significance. The usual approach is some sort of data indexing, typically time. Once you have an indexing scheme, you have to match the events of interest to the index. Up to now, essentially manual means have been relied on. A time log is maintained during the test or a strip chart is manually reviewed afterwards to identify key times. Artificial Intelligence (AI) techniques are currently being developed to perform this event identification task.

Concerning other aspects of data handling and analysis, in 1984, we invested in the development of an interactive analysis software package called DataProbe by Bolt Beranek and Newman Inc. (BBN). It was a good decision. Once the data is time indexed on a per frame basis, and the positions of the variables in a frame are mapped, DataProbe pretty well takes care of the rest. It can open multiple input devices such as a combination of tape and disk drives. It then extracts from the various devices all of the variables of interest in a given time period. The values of interest are cached for efficient access. DataProbe then provides a wide spectrum of signal conditioning and other mathematical functions with which to manipulate the cached data. There are also several choices for output to record results.

COMMON DATA BASES

Since "smart" weapons interact with their situational environments, additional data from other sources must be analyzed to get a true perspective of the performance of the weapon. In torpedo testing, there is typically a target vehicle which simulates an enemy ship. Most of our targets are designed to acoustically respond to an attacking torpedo. By comparing the signals received and transmitted by the target against the signals received and transmitted by the torpedo, another perspective of what is actually occurring under the water is provided. It should be noted that a given vehicle may generate multiple data recordings of different sets of variable values which are considered independent sources. When all this data is combined with instrumented range data, a pretty complete picture of the situation can be developed. (That is the theory anyway. In practice it's a little more difficult.)

Time synchronizing all data sources in order to form a common data set adds another level of complication. Assuming all the sources of data are some how time tagged, the approach is to locate a common event in each of the data sources and to offset each source's time tags to match at that event. However, there are not that many common events that all the sources will record. The precise location of a given event in each source's data set may require either manual inspection or a complex set of search criteria if done computationally. And even if the original time tagging of each source is reasonably accurate, some interactive resynchronization (fudging) may still be required at each point of interest to get a reasonable result.

There is another practical challenge to merging the data from all sources into a common data base. How do you form, store, and access in a reasonable amount of time; a common data base which is GigaBytes in size and includes thousands of distinct variables. We are still working on that one. Currently, we analyze individual sources via independent processes and then compare results at times of interest.

I suspect that the above facets of data handling are fairly typical for the testing of any type of “smart” weapon and have many similarities to large data handling/analysis efforts in general. Figure (2) is a flow diagram typical for multi-source test data. However, there are some unique elements to undersea testing.

UNIQUE ELEMENTS OF UNDERSEA TESTING

It must be nice to visually watch a good portion of a test while knowing that significant quantities of test data are being sent to your ground station via radio telemetry. On the other hand, it is nice after the test to recover an intact torpedo with an onboard recording device full of data (hopefully unexposed to sea water) rather than some scrapes of twisted metal. Since radio telemetry is not possible underwater, torpedo testing depends on large capacity recording devices and associated encoding electronics which can be packaged in the vehicle and protected until recovery.

Another significant difference is that range tracking and weapon/target interactions are all based on underwater acoustics rather than various forms of electro-magnetics. While the acoustic wave equation is identical to the electromagnetic wave equation except for a few wrinkles like polarization, there are enormous differences in the engineering parameters involved. The speeds of propagation differ by a factor of 200,000. The speed of acoustic signals is also significantly variable depending on the temperature, depth, and salinity of the water along the signal’s path. The variation of the index of refraction in a few meters of water depth is more than 100 times greater than it is from the bottom to the top of the atmosphere. The available EM bandwidth in air and space is at least 1 million times greater than acoustics in water. The relative Doppler for torpedoes is 10,000 times greater than for air missiles. Multiple paths with a dispersion of travel times for a given acoustic signal commonly occur. The variable speed of the signal and the uncertainties as to what path a received signal actually took makes precise ranging difficult. There is also a lot of noise in any large body of water. These noises are from the wind, waves, shrimp, fish, sea turbulence, unrelated shipping, and even the self noise of the vehicle doing the transmitting. All this noise clutter along with various attenuation effects reduces the signal to noise ratio of the received signal to pretty low levels. On the other hand, most everything in the water makes some sort of characteristic noise, particularly target ships. So much use can be made of passive signal collection with frequency domain analysis to identify items of interest.

There is an additional aspect to underseas testing which always adds a bit of zest. The exact state of the test environment is usually unknown. Environmental variables such as temperature which determine the engineering parameters of the test can only be approximated along the test route. Further, the very nature of the undersea environment under varying conditions is still being explored. In essence, every torpedo test is an experimental probe into the nature of the environment, i.e., the environment itself is being tested along with the weapon. Needless to say, this adds additional complexity to the normalization of data and the determination of cause and effect.

As previously discussed, there are many similarities in torpedo testing to the testing of other smart weapons as far as data handling and interactive analysis techniques. However, torpedo testing is performed in an environment remote to the observer and relies on recovery after the test rather than essentially real time observation and data receipt. This remoteness combined with the engineering parameters involved and the uncertainties of the environment make undersea testing a unique undertaking.

IN THE FUTURE

In the future, undersea weapons are expected to continue to get “smarter” along with other advanced weapons. If past trends are any indication, there will be an associated increase in required data rates and capacities. As previously mentioned, the bulk of the data in undersea testing is recorded and stored by the vehicle being tested. In the near future, we are going to need small, ruggedized, digital recorders; with read/write rates on the order of 5 MegaBytes per second, and 5 or more GigaBytes of capacity. It would really be nice if the recorder can be made hardware and software compatible with a range of hosts. The development of common busses such as the SCSI and Ethernet busses is a step in the right direction.

However, the translation or emulation software to take advantage of the common busses across various hosts and operating systems is still lacking. We have run into this problem while trying to develop a common, intermediate, data storage system. By intermediate, I am referring to the storage of data after its been processed and prior to it being re-input for analysis. Data from different sources is typically processed by a variety of hosts with various operating systems. Along with a broad range of compatibility, the intermediate storage media needs to be high capacity with corresponding fast access to handle all the data involved. It must also be capable of high read/write rates to keep from slowing down the high speed host processors that have become a reality. And of course, it needs to be relatively inexpensive. We would also like to use this media for data distribution to other facilities which again requires compatibility with various computational resources. The digital 9 track tape used to fill the bill quite nicely. It is now severely rate and capacity limited. We are looking for something to replace it. There must be 10 different vendor representatives out there who have labeled me as "difficult" (or worse) after I have told them what I want to hook up to what, and how fast I want it to go!

In the future, we will be merging multiple sources of data into a common data base and using AI techniques in data processing and event identification. We are also considering a greater participation in the area of performance simulation. These plans will require a significant upgrade of our processing and data storage resources. We have already started the development of a communications network which will allow remote terminal access by other government related projects to our interactive analysis facilities.

SUMMARY

NUWES has been testing and analyzing the performance of undersea weapon systems since World War II. While undersea testing is a unique undertaking, we have gained a lot of experience in data processing and interactive analysis techniques which have a common application to various test situations.

NUWES is committed to a Total Quality fulfillment of its mission of performance testing and evaluation of undersea weapon systems. As the weapons get "smarter", so will we. We are also upgrading our resources to support other government related projects which can benefit from the data processing and analysis expertise we have developed over the years.

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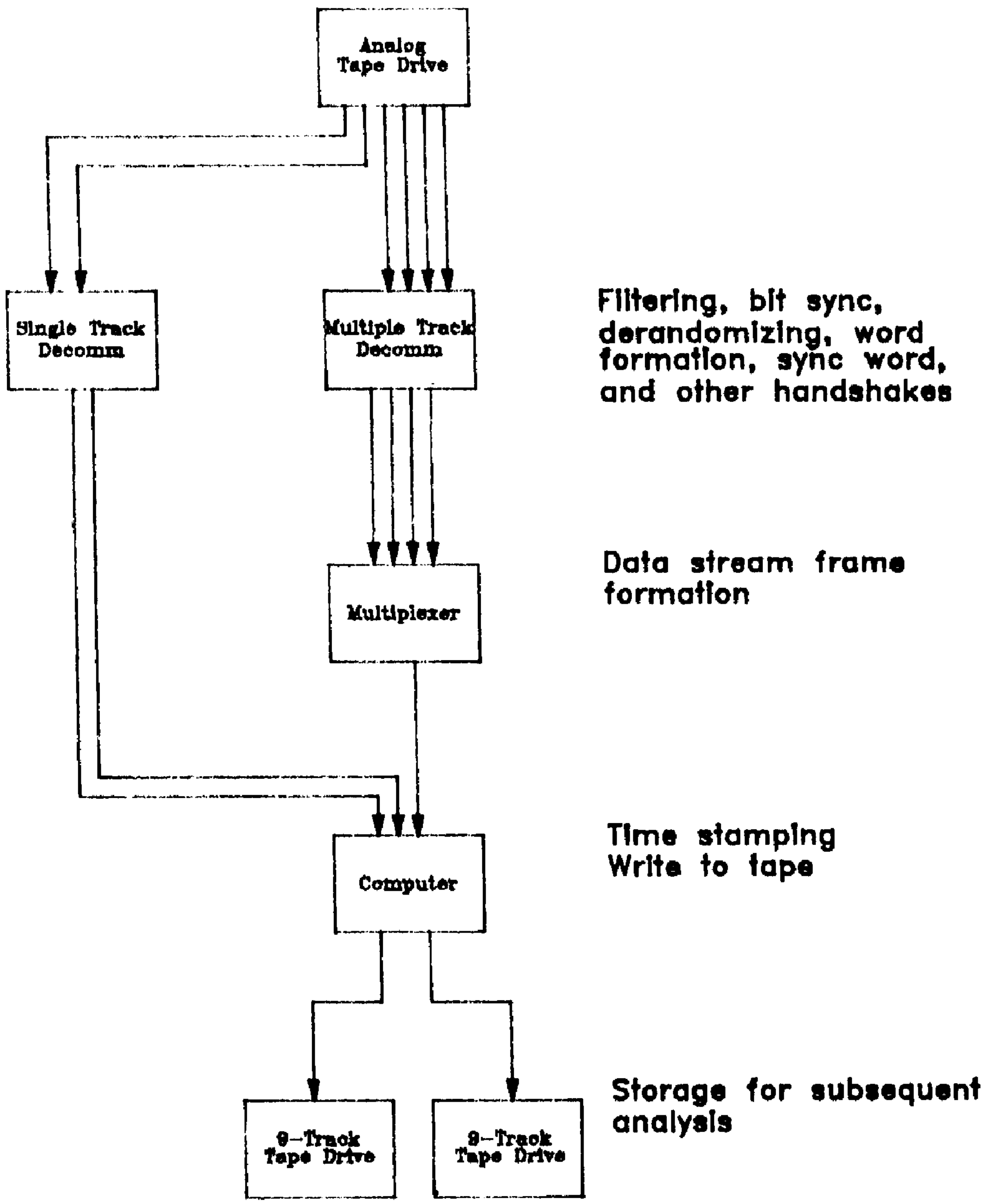

Figure (1)
MK48 ADCAP Torpedo Data Preprocessing

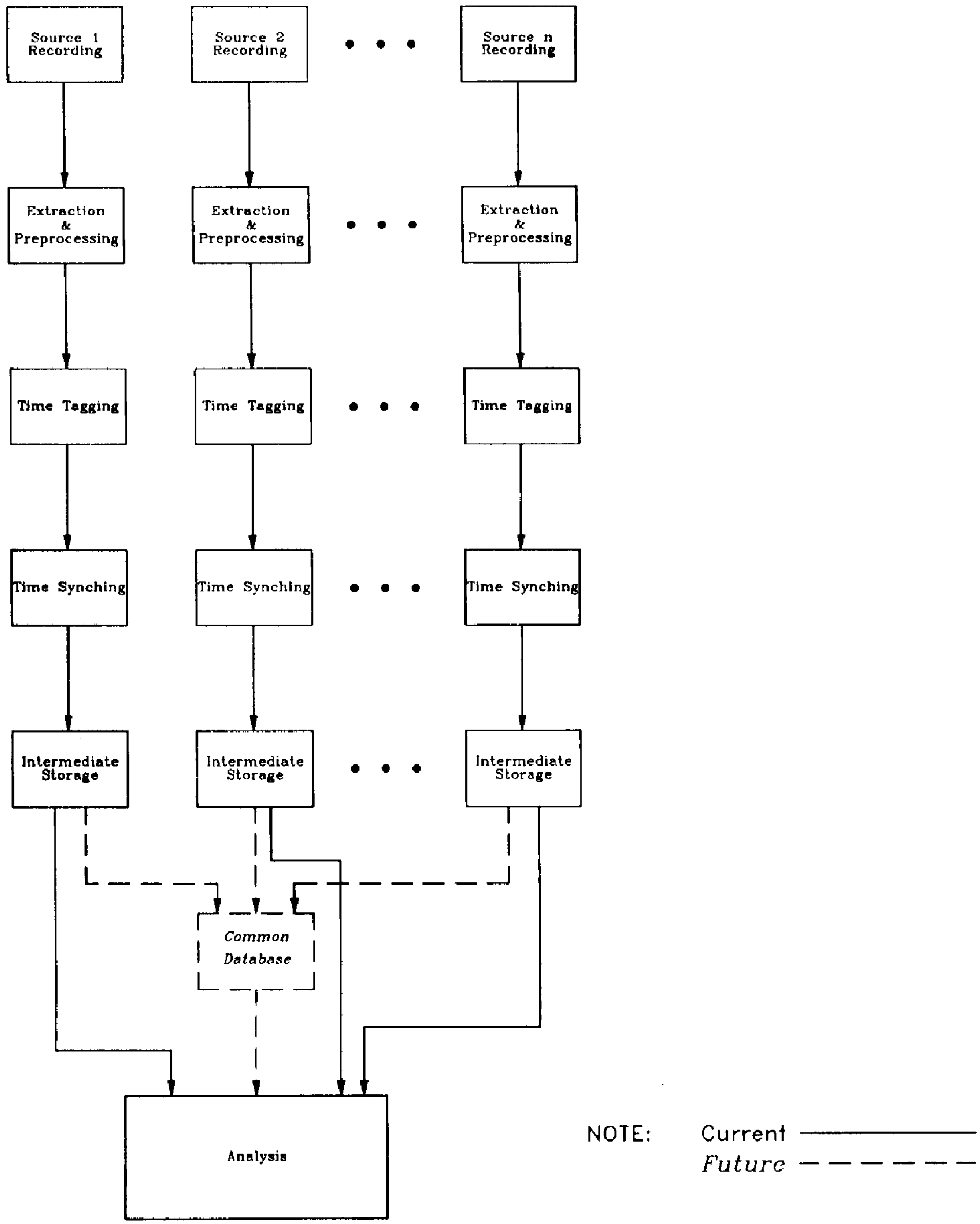

Figure (2)
Typical Test Data Flow