AUTOMATED ACOUSTIC DETECTION AND PROCESSING FOR THE ADVANCED RANGE INSTRUMENTATION AIRCRAFT SONOBUOY MISSILE IMPACT LOCATION SYSTEM

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ABSTRACT

Recent advances in acoustic detection and array processing have led to a new, state of the art, Sonobuoy Missile Impact Location System (SMILS). This system was developed for the 4950th Test Wing by E-Systems and the Johns Hopkins University Applied Physics Laboratory to support ballistic missile testing in broad ocean areas.

The hardware and software required to perform the SMILS mission were developed in two different areas: 1) The flight system, installed aboard the Advanced Range Instrumentation Aircraft (ARIA), which provides everything necessary to guide the aircraft to the target area of Deep Ocean Transponders (DOTs), deploy sonobuoys, recover signals from the sonobuoys, and to process the recovered signals. The sonobuoy positions and impact locations of reentry vehicles are determined aboard the aircraft in real-time by telemetering the acoustic signals sent from the sonobuoys via Radio Frequency (RF) link to the aircraft. These acoustic signals are also recorded on analog tape in the aircraft. 2) The Post Mission Analysis System (PMAS), located at the 4950th Test Wing, processes the analog tapes recorded by the aircraft to do more sophisticated Processing than that performed on the aircraft, providing higher resolution of impact times and positions.

This paper addressees the theory of PMAS operation and the specific approach used to perform automated acoustic detection of both narrow and wide band acoustic signals. It also addressees the processing technique employed to determine sonobuoy navigation and impact scoring.

“Key words: Sonobuoy Missile Impact Location System (SMILS), ballistic missile testing, Advanced Range Instrumentation Aircraft (ARIA), Deep Ocean Transponder (DOT), acoustic processing.”

INTRODUCTION

The ARIA fleet, comprised of three EC-135E and four EC-18B aircraft, are employed as flexible airborne telemetry data recording and relay stations. These aircraft were designed and developed to supplement land and marine telemetry stations in support of Department of Defence and NASA space and missile programs. ARIA support of ballistic missile programs requires the aircraft to fly to a broad ocean target area, receive telemetry from instrumented reentry vehicles and equipment sections, provide photo documentation of the reentry bodies, collect meteorological data from the ocean’s surface up to 100,000 feet, and launch a pattern of sonobuoys which will telemeter acoustic data to the aircraft, allowing the impact positions and splash times of the reentry bodies to be “scored”.

The SMILS data collection operates in the following manner: a pattern of 16 sonobuoys is air deployed over an array of Deep Ocean Transponders (DOTs) whose geodetic locations are known. The DOTs are interrogated periodically by three of the sixteen sonobuoys using an acoustic signal of identical frequency (16 KHz) but of different repetition rates. This interrogation is also received by all other buoys in the pattern. Each DOT in the array, when interrogated, replies with it’s own acoustic signal of unique frequency (between 7.5 and 12 KHz) for its position in the array. These acoustic signals are then received and telemetered to the aircraft by all sixteen sonobuoys. Ten of the sonobuoys in the array are active surface pinging sonobuoys that ping at unique repetition rates, but all on the same acoustic frequency (2.33 KHz). These signals are received by all sonobuoys in the pattern and are relayed to the aircraft via an RF link. When each of these interrogating or surface pinging sonobuoys pings, it also sends a marker tone (4 or 4.66 KHz respectively) to the aircraft via an RF link to identify the source of the ping. The remaining three sonobuoys in the pattern are passive sonobuoys that are little more than microphones. These passive sonobuoys receive acoustic information from DOT replies and surface pinging sonobuoys and transmits this acoustic information to the aircraft via an RF link. The last acoustic signal of interest is the reentry vehicle impact. This high energy, broad band signal is received by all sonobuoys in the pattern and is transmitted to the aircraft via an RF link. This information along with Inter-Range Instrumentation Group (IRIG) timing provides all the information that is necessary to perform the scoring operation. All of this information is recorded on 14 track analog tapes along with a servo reference signal to control tape playback at 7.5 inches per second.

The Post Mission Analysis System (PMAS) of the Advanced Range Instrumentation Aircraft Sonobuoy Missile Impact Location System (ARIA/SMILS) is an advanced set of software installed on a MicroVax III computer in conjunction with a Honeywell Model 97 Magnetic Tape Recorder/Reproducer System, a time code processor, and associated input and output interfaces. The software is comprised of two functional areas, the Post Mission Pre-Processor (PMPP) and the Post Mission Processor (PMP). The PMPP provides the hardware and software necessary to recover the acoustic signals from the analog tape. It determines the time of reception and frequency of each ping received at each sonobuoy.

The PMPP also determines the reception time of each reentry vehicle impact splash at each sonobuoy. The recovered acoustic data is passed on to the PMP portion of the PMAS, in the form of data tables. This data is then processed into highly accurate geodetic locations and time of reentry vehicle impacts.

POST MISSION DATA TRANSFER

The acoustic data from the mission is recorded on two 14 track analog tapes. On each tape, one track contains the IRIG-B time code and another contains the servo reference signal used to control tape playback speed. Twelve tracks remain an each tape for recording of sonobuoy acoustic data. In addition to the sonobuoys mentioned above, a special purpose sonobuoy is launched early in the mission to measure the sound velocity profile of the ocean environment. This data is also recorded on analog tape. These tapes are individually played back on a Honeywell Model 97 recorder. Each tape is played into a two channel analog-to-digital (A/D) converter, allowing only two of the twelve tracks of sonobuoy data to be sampled at a time.

The PMPP portion of the PMAS has been designed to handle the data transfer between the analog tapes and the MicroVax storage disks and provides three major processing functions. These three functions provide their results in three tables for further analysis by the PMP. These three functions are Ping Processing, Impact Processing, and Sound Velocity Processing.

PING PROCESSING

Every 200 milliseconds, two channels of acoustic data on the analog tape are sampled by the A/D converters. A third channel of time marks are added and the resulting data is stored in an input data buffer. The three channels of data are interleaved throughout the entire data buffer. The two acoustic channels are deleaved into two continuous acoustic data buffers and the data is converted to floating point. A Fast Fourier Transform (FFT) is performed on groups of data samples from each acoustic data channel. The FFT determines the frequency content of each of the groups of raw data samples and returns the frequency component amplitude in a range of 0 to 31750 Hz in 250 Hz increments. The data is then examined for the presence of acoustic events of interest using a four step process.

Event Detection

An event, in this case a ping, is detected by comparing the present amplitude of a particular frequency of interest to a past history (noise) of that same frequency. When the signal to noise ratio increases beyond a certain threshold, we say that a potential event has occurred. The sonobuoy marker tones are determined when the frequencies of interest exceed an absolute threshold. To determine if the event is valid, it must satisfy the following conditions: 1) the time duration of the event mist fall within a specified range; 2) the signal to noise ratio must exceed the control parameter at least once; 3) the noise history must not exceed its control parameter.

Edge Detection

Detection of the beginning of the event is accomplished at the .125 millisecond level by sliding a table of values produced by a sinusoid at the frequency of interest across the raw sample and computing the correlation between the two over a 8 millisecond correlation interval. (See Figure 1-1)

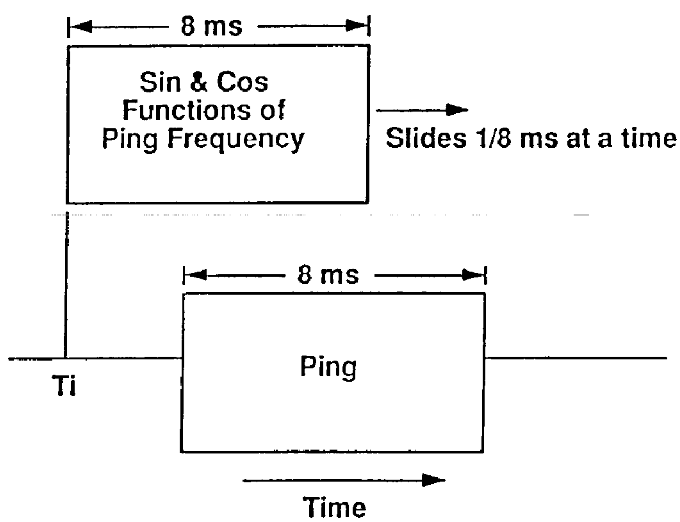

Figure 1-1

Sorting

The PMPP examines all the event detected ping data and using the edge detection times, determines the presence of pings repeating at a nearly constant period for all the various frequencies encountered. The periods are determined by subtracting the first ping time from subsequent ping times then dividing each result by successively increasing integers until a predetermined valid period is obtained. A check is then made to verify that a sonobuoy was operating with that period and that the period repeats. This process continues until all the various pings are discovered. The periods are then used to predict the occurrence of a sequence of pings at the given period and frequency. If pings can be found which match the predicted period, these are considered to be valid. All other pings will be considered false alarms.

Linking

This portion of the PMPP is activated after data from all sonobuoys has been processed. It relates ping receipt times at each sonobuoy with the transmit times at the sonobuoy that caused the received ping. The result is one of the three files to be used by the PMP for final scoring.

IMPACT PROCESSING

There are two impact processing routines available in the PMPP. Impact detector #1 tends to be quick; however, it is very sensitive to parameter adjustments. Impact detector #2 runs much slower but does not exhibit the same sensitivity as impact detector #1, resulting in excellent impact detections.

Impact Detector #1

This algorithm makes use of four windows to examine the data: the noise window, the signal window, the data window, and the FFT window. The algorithm performs three tests on the data and must pass before an impact is considered detected. The first test compares the signal and signal to noise ratio to a controlled signal threshold and signal to noise threshold, respectively. The purpose of this test is to detect the increase in the amplitude of the data coincident with an impact and to ensure that the signal data is high enough for a potential impact. The second test is the FFT test. The purpose of the FFT test is to reject reverberations which have a lower energy content in the higher frequency regions. From the frequency spectrum data, the energy in two frequency bands is computed. The ratio of the energy between the upper and lower frequency bands is computed and compared to a controlled threshold. The third test is to reject short duration noise which would otherwise be detected as an impact. This test compares the mean absolute value of the data in the data window to a controlled threshold. If one or more of these tests fail, the windows are moved ahead by one millisecond and the tests are repeated. If all three tests pass, the windows are advanced enough to avoid multiple detections of the same impact due to fluctuations in the noise level associated with an impact. The output from Impact Detector #1 is one of the three files to be used by the PMP for final scoring and contains a listing of impact detection tunes for each sonobuoy in the pattern.

Impact Detector #2

This routine also uses four windows: signal, noise, FFT, and data. Impact detector #2 uses three levels of processing to detect impacts. In level 1, the signal to noise ratio is computed and compared to the controlled threshold. If the signal to noise ratio is greater than the threshold, then level 2 processing begins. In level 2 processing, the data is moved backwards slightly and a counter is initialized to one. The windows are then slid forward in one millisecond intervals and the signal to noise ratio, power in the signal, power in the upper and lower frequency bards, and variance of the raw data are computed and saved and the counter is incriminated by 1. This continues until the signal to noise ratio drops below a controlled threshold. Once the signal to noise ratio drops below the controlled threshold, the count is checked to see if it is greater than a minimum threshold. If it is below the minimum threshold, the routine reverts back to level 1 processing, otherwise level 3 processing begins. In level 3 processing, the data from level 2 is averaged and the values of the upper to lower frequency power ratio and the upper frequency power to variance of the raw data averages are computed. Finally, if the two computed values are greater than their corresponding controlled thresholds, the detection is consider valid. The output from Impact Detector #2 is one of the three files to be used by the PMP for final scoring and contains a listing of impact detection times for each sonobuoy in the pattern.

BOUND VELOCITY PROCESSING

The PMPP invokes a routine which reads the analog tape to produce a file containing frequency versus time. This file is the last of the three files that is passed on to the PMP for final data processing. The data from the sound velocity sonobuoy is a sinusoidal frequency, controlled by a voltage controlled oscillator. The frequency of the data signal from this sonobuoy is directly proportional to the sound velocity of the ocean. Knowing the sink rate of the probe and the time of release of the probe, it becomes a trivial task to calculate the sound velocity versus depth profile for the ocean environment.

POST MISSION PROCESSOR

The PMP portion of the PMAS processes the three input files from the PMPP to produce highly accurate solutions for the RV impact times and geodetic positions. It accomplishes this by using a number of operator entered database files containing information such as DOT positions, mission day and time, sonobuoy definitions, and historical sound velocity data. The PMP may be divided up into six functional areas: Controlling Software, External Functions, Load PMP Inputs, Navigate Buoys, Solve Impacts, and Report Results.

Controlling Software

This is the top-level software from which all PMP modules are invoked. This software presents screen menus, manages the operator interface, handles file allocation and usage, checks completion codes from all subordinate processes, and maintains log files to document all PMP operational runs.

External Functions

This software manages the database files in which DOT array coordinates and historical ocean profiles are stored. Updates to these files and creation of new files is handled under menu control by the controlling software.

Load PMP Inputs

The data files loaded are: a file of sound velocity data giving frequency versus tine from the PMPP; a file of detected pings for each sonobuoy from the PMPP; a file of detected impact splashes for each sonobuoy from the PMPP; and a sonobuoy definition file from an external database. The data loading software also invokes sound velocity processing software which processes the PMPP sound velocity file to obtain sound velocity versus depth and then merges historical data by means of a decaying exponential technique to limit discontinuity at the transition point, completing the profile down to the ocean floor. Ray tracing and curve fitting routines are used to compute the harmonic velocity, average surface velocity, surface and bottom gradients, and the coefficients of a third order refraction correction polynomial which yields the error in the sound travel time introduced by assuming straight line travel at the harmonic velocity. The refraction correction data, which is a function of the slant range, is used to correct sonobuoy-DOT and DOT-sonobuoy ping propagation times.

Navigate Sonobuoys

Because the PMPP has identified the transmitter corresponding to each received acoustic event at each sonobuoy based on a known pinger period, estimated ranges are associated with the signal paths and a iterative, batch least-squares solution for sonobuoy positions versus time is produced. Sonobuoy solutions are produced in the form of a set of position/velocity/uncertainty solutions for a series of sequential time intervals. Each interval represents a new batch least-squares solution for the set of sonobuoys. The starting estimate for each sonobuoy is set to the solution results from the previous interval, except in the first interval, where a standard sonobuoy pattern is assumed with known positions for each sonobuoy. The software iteratively computes estimates of sonobuoy positions based on the known DOT positions and the measured ping transmit times, except in the first interval, where only the known DOT positions are used and all surface pingings are omitted in generation of the solution. These measured times are corrected for the effect of refraction by applying the cubic refraction correction polynomial to compute the travel time adjustments. If convergence of the least-squares solution occurs before reaching the minimum number of pings and DOT responses, then the solution is considered valid and returns the sonobuoys position and uncertainties in position. If the solution for the position of the sonobuoy during one or more intervals does not converge, then the sonobuoys position will be interpolated for that interval using the previous and next good solution. The sonobuoy navigation software also solves for the surface and harmonic (vertical) components of sound velocity simultaneously along with the uncertainties for these values.

Solve Impacts

Because any least-squares technique requires some starting estimate, the software first performs a "grid search" to identify locations in the DOT array that are probable impact points based on an assessment of the splash table. At each detection time, the software also interpolates sonobuoy positions to be used in the impact solution. Each splash detection is then paired with each of the estimates in an attempt to produce a least-squares impact solution which satisfies convergence and uncertainty criteria, with a shrinking window editor which rejects false or unrelated splash detections. The software automatically removes any false solutions that are due to bubble-collapse phenomenon. Once all criteria is met to validate an impact and obtain its position and time of occurrence, the position, time, and their relative uncertainties are stored as valid impact solutions. DOT array uncertainty parameters are used to produce geodetic uncertainty and error ellipse components for each valid impact and a set of final impact solutions are generated and saved.

Report Results

This software produces graphical and tabular Output to printer, screen, or magnetic tape, of the sonobuoy positions, reentry vehicle impact positions and times, and sound velocity reports along with all associated errors. This software also allows the selection of the output units of measure.

SYSTEM PERFORMANCE

The Post Mission Analysis System has been undergoing operational testing since May 1990, using data collected from the ARIA/SMILS aircraft supporting United States Air Force and Navy ballistic missile test programs. Repeatability of solutions has been demonstrated through every stage of the system. Typical scoring accuracies are less than 1 millisecond in time and less than 4 meters uncertainty in relative [x,y] positions. To date, all reentry vehicles for each ballistic missile test support have been scored with final test results being reported to the user. This process of reading the tapes and processing the data, Producing the final ballistic missile scoring report from this state of the art, highly accurate system takes less than 3 working days.

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