Project Report: Development of a Portable Passive-Acoustic Bedload Monitoring Surrogate for Non-Experts

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Introduction:

Passive acoustic methods for monitoring bed load transport have been explored for some time. The acoustic properties of bed load discharge of a single-sized particle was investigated in a laboratory flume (Johnson and Muir, 1969). The acoustic properties of impacting glass spheres of mixed sizes was studied (Thorne, 1985) by placing the spheres in a submerged rotating drum. Laboratory work has consistently shown that the sound generated by impacting gravel particles can be used to determine a theoretical relationship between total discharge and acoustic energy. Recent field studies have been conducted (Barton, 2006, Barton et al., 2010) using hydrophones to detect gravel movement in the Trinity River. To continue this research, a passive acoustic system was tested at four different field sites: the Trinity River in Weaverville, Ca; the Elwha River in Port Angeles, CA; the Walnut Gulch Watershed near Tombstone, AZ at the Lucky Hills sub-watershed; and Bear Creek in Denver, CO. While physical bed load samples were taken in conjunction with each deployment, the nature of the physical sampling varied. Graham Mathews and Associates (GMA) was responsible for sampling at both the Trinity and Elwha rivers. The data from the Trinity River deployment shows positive trends between recorded acoustic signals (rms voltage) and bed load transport (Fig 1).

The system as it was deployed in the aforementioned field studies (Fig 2) was comprised entirely of laboratory-grade equipment. This equipment had a much larger bandwidth than was required, and many of the components were both delicate and unwieldy. Specifically; for each channel being used, there were four wiring connections that had to be made. Each channel also required its own preamplifier, which had three settings that must be chosen correctly and which also required 12 VDC power. Finally, each channel was run into an NI data acquisition system which was interfaced with a laptop. The system could only be deployed for a few hours at a time, and was not suitable to be left overnight. In addition to all of these issues, the hydrophone cables themselves were very delicate easily damaged or broken. The purpose of the work detailed here was the development a more robust and user-friendly system.



Figure 1: Acoustic data shown with physical measurements taken by Graham Matthews and Associates at the Douglas City site on the Trinity River, CA



Figure 2: Lab-grade hydrophone system

Design and Instrumentation

To begin the re-design of the system, it was decided that a more robust hydrophone would have to be selected. The RESON hydrophones were simply too expensive, too delicate and too sensitive to ever be incorporated in a viable portable system. Three different commercially available hydrophones were tested in the lab at the NCPA. The hydrophones were tested for overall sensitivity, power requirements as well as a qualitative assessment of their durability. The hydrophone chosen was an HTI 96-MIN Exportable (HTI, 2015). The hydrophone has a built-in amplifier which requires a DC voltage of between six and twelve volts. The inclusion of the pre-amp drastically reduced the wiring and overall bulk of the system; reducing a delicate wire, a pre-amp, two more cables and a battery connection down to one wire and one 9-volt battery connection.

The second step of the re-design was the data collection process. A Zoom H4N wave recorder (Zoom, 2015) was chosen as the data collection device. This wave recorder offers numerous advantages over a laptop-based acquisition system. The wave recorder has several operating modes. The mode of interest is a two input channel recorder. The recorder has the ability to choose from several combinations of sampling rate and bit range. After lab testing and experience from previous deployments, a sampling rate of 48 kHz and bit range of 16 bits was chosen. When set to record, the H4N will record to a .wav file until the file reaches 2 GB in size (roughly 3 hours of two-channel acoustic data at these settings). Once the file reaches this size limit, the H4N automatically starts a new file and names the file numerically. The time missed between stopping a file and starting a new one is minimal since the recording is done in a streaming fashion. In this way, the system can be set to record and left until the SD card used by the H4N is full, or until the batteries run out. The manufacturer of the H4N states that the recorder can handle up to a 32 GB SD card, or approximately 48 hours of data at the setting used. The H4N is designed to run off of either 2-AA batteries, or a 5 VDC input. Testing and experience indicate that a fresh set of AA batteries will last between 5 and 7 hours. However, a 12 VDC to 5 VDC stepper was purchased and wired such that the H4N could be connected to a 12 V battery (such as a car battery or any of several smaller options). Under these conditions, the limiting factor for length of recording time becomes the SD card. It is estimated that the system could be left to record unattended for at least 36 hours with no problems.

Field Deployment

As of the time of this writing, the system has been deployed in two different locations: Halfmoon Creek near Leadville, CO and the Walnut Gulch watershed, near Tombstone, AZ. To prepare the system for field deployment, all of the components were fitted into a modified weather-proof case (Fig 3) for ease of transport and operation as well as protection from the elements.



Figure 3: Field box containing the wave recorder, DC power stepper, two parallel 9V batteries with connections for two hydrophones and an optional external 12VDC connection

A protective case was designed and fabricated for the hydrophones (Fig 4). This case was designed to reduce flow turbulence as well as to provide a convenient means of mounting. The back end of the case is designed to fit snugly into a standard 1" schedule 40 PVC pipe coupling. There is a through-hole in the case so that a pin can be inserted through the coupling to secure the hydrophone. Thus the hydrophone can be mounted in a variety of ways so as to be adaptable to as many settings as possible.



Figure 4: Exploded view and closed view of the custom case for the HTI hydrophone

The deployment at Halfmoon Creek was the first test of the longevity of the system. It was deployed continuously for nearly a month. The mounting used at halfmoon creek was intricate. First, a standard t-post was driven into the bed. Then, ribbed plastic piping was tightly slid over the post to provide a circular cross-section to better control the hydrophone's height above the bed and to reduce external noise and vibration from the structure itself. A fairing typically used for small aircraft was introduced to the structure design. The fairing possessed a tear-drop shape, best fitted to reducing drag and interference of water flow around the post. The fairing and hydrophone assembly is shown in Figure 5.



Figure 5: Teardrop fairing and hydrophone assembly as deployed at Halfmoon Creek in Leadville, CO

Once the hydrophone and fairing were placed over the ribbed tubing on the t-post, the cables were strung out of the top and over to the bank. The method of getting the cables back to the bank depends greatly on the environment. The only method that should be absolutely avoided is simply letting the cables float in the water. This provides numerous hazards to the system. Thus the cables should either be strung across the river or buried. At Halfmoon Creek, there was no possibility of burying the cables, so they were strung to the bank.

The deployment at Walnut Gulch required a different mounting approach (Fig 6). Two sets of hydrophones were deployed at different locations along the reach. Each set consisted of two hydrophones fixed relative to each other. Since the stream being tested is dry except during storm events, the cables were easily buried and run to a structure on the bank.



Figure 6: Two hydrophones fixed relative to each other, as deployed at Walnut Gulch in Tombstone, AZ

These mountings showcase the flexibility and adaptability of the system to various conditions and testing desires.

System Operation

This section provides a list-style set of instructions for operating the current system. Note that settings and parameters may change in the future. This is a very basic set of instructions. Any actual deployment will require adaptations and adjustments.

- 1) Attach hydrophones to the exterior of the weatherproof box: note the designation of 'Channel 1' and 'Channel 2' specific to the deployment
- 2) Check the voltage on the 9V batteries: if they are below 8.5, replace them.
- 3) Check the voltage on the AA batteries in the back of the H4N (or the 12V battery if using external supply).
- 4) Insert an SD card into the H4N
- 5) Turn on the H4N and wait until it indicates it is ready to record
- 6) Verify desired settings: these include
 - a. Default file name
 - b. Sampling frequency (48 kHz)
 - c. Bit range (16 ibt)
 - d. File type (.wav NOT mp3)
 - e. Record Level setting (set to 1)
- 7) Select both '1' and '2' as the input (simply press either button)
- 8) Press 'REC' button once to put the system in standby mode; verify that the sound indicator bars are active
- 9) Press 'REC' once more to begin recording
- 10) When finished recording, press 'REC' again.
- 11) SD card can now be removed and the data files transferred to a permanent location

Suggested Practices

Location of the hydrophones:

Vertically:

As a standard practice, it has been decided that the hydrophone should be placed as close to the bottom as possible while avoiding impacts. Thus the hydrophone should be located at a height above the bed equal to the maximum expected bed load material diameter (D90 for example). However, care should be taken to ensure that the hydrophone remains submerged.

Cross-Section:

Placement of the hydrophones relative to the cross-section of the testing environment is still an active area of research. Ideally, the hydrophones could be placed such that they 'investigate' the entire cross-section of the river. However it must first be known exactly what area they are capable of investigating, and this is currently under investigation. Until this is known exactly for each specific deployment, it is the recommendation of the authors that as many hydrophones as is feasible are placed equidistant across the entire cross-section.

With respect to flow:

Each of the deployments to date have had the hydrophones oriented *with* the flow, *downstream* of the mounting post. In any other orientation, significant stress can be put on the mounting brackets.

Acoustic Calibration

One key parameter of any acoustic device is the sensitivity; or the amount of voltage created for a given acoustic signal. This sensitivity is very often frequency dependent. An experiment was designed to determine the frequency response of the cased hydrophone. An underwater acoustic source was made to generate individual tones which were simultaneously captured by the cased hydrophone and a RESON TC4013 hydrophone. The Reson hydrophone is a scientific-grade hydrophone with a known flat frequency response and was calibrated using a pistonphone. By comparing the signals received on the cased hydrophone and the Reson, the sensitivity of the cased hydrophone was determined and is shown in Figure 7. The data indicate that the nominal sensitivity is $-132 \ dB \ re: \frac{1V}{\mu Pa}$. While the sensitivity does decrease slightly with increasing frequency, it is reasonably flat across the frequencies of interest.



Figure 7: Frequency response of the portable system

Conclusions

Researchers at the National Center for Physical Acoustics have developed a portable hydrophone-based recording system for the purpose of acting as a bed load monitoring surrogate. The system uses two HTI 96-MIN Exp hydrophones as sensing elements. A custom enclosure was constructed to reduce flow noise around the hydrophone and to provide a variety of mounting options. The hydrophones are connected directly (via waterproof connections) to a weather proof case. Inside the case are two 9V batteries in parallel used to power the hydrophones. Also inside the case is a Zoom H4N recorder. This recorder has the ability to simultaneously measure both channels at 48 kHz with 16 bit resolution. The recordings are streamed to .wav files on an SD card. When the file reaches 2GB a new file is automatically created and timestamped. Finally, the box has been wired to allow an external 12V battery to power the H4N in the event of deployments lasting longer than a few hours: without this battery the AA batteries inside the H4N would have to be changed. The system has been deployed twice. Most notably at Halfmoon Creek in Leadville, CO where it was run nearly continuously for almost a month.

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