Horizontal ADCP for Remote Mapping of Currents

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Abstract - Harbors throughout the world realize the importance of water flow information of the main waterways for ship guidance. The most ideal measurement would be real time depth averaged flow information through the water ways. Reliable estimates of discharge may also useful for a variety of organizations interested in monitoring rivers and channels. Both of these applications may be provided by a Horizontally mounted ADCP (HADCP). However, because each sound beam has a finite opening angle, this generally results in the reflection of sound against the bottom and the surface. These reflections may contaminate the measurements of the water column. A specially designed and modified 300kHz RDI workhorse unit was used to take data at two different river locations: Jersey Point on the San Joaquin and Walnut Grove on the Sacramento river. The unit is unique in that two pairs of vertically stacked transducers are used to obtain narrower beamwidths than a standard unit. Additionally, special firmware was installed to allow the raw pressure time series from each transducer to be recorded. Algorithms to successfully detect contamination from the surface and the bottom were used to assess data quality. Provided care is used in site selection and installation, the unit works well and is capable of producing profiles to about 100m as well as estimates of discharge. The effective range of the system varies, even in locations which are not thought to be highly stratified. This indicates the need for real-time algorithms to assess data quality to be included in the firmware of such an instrument.

I. INTRODUCTION

Two primary applications for horizontal ADCP (HADCP) sonars are (i) to map currents on rivers or near ports and harbors to assist ships to safely navigate locations which have time-varying and dangerous currents and (ii) to enable estimates of volumetric discharge of water flow on rivers and channels for routine monitoring.

These measurements may be provided by acoustic velocity meters (AVMs), although installation and equipment costs tend to be expensive. The AVMs also provide only a mean velocity across the channel. The measurements may also be performed by an ADCP mounted on a boat performing transects, but this is somewhat time-consuming and cannot provide a continuous stream of information at all times. Bottom mounted, uplooking sonars run the risk of being dredged or having their cables damaged by numerous causes.

A horizontally mounted ADCP is an option for these kind of measurements. Two transducers send sound horizontally through the water. The sound will reflect on suspended material and will undergo a Doppler shift. The shift is a measure for the flow velocity in the direction of the sound beam. Taking the sound travel time into account one will know the flow velocity at certain distances from the instrument by combining the two velocity components in the direction of the beams.

However, the sound has a finite beamwidth which causes it to spread out as a function of distance from the transducer. A consequence of this is that, after some period of time, the sound will reflect against the bottom and the surface. These reflections will, in general, contaminate the measurements of the water column. In the case of reflections from the bottom, the velocity profiles generally become biased to lower velocities because the bottom usually does not move quickly. It is harder to predict the influence of the surface reflections. If the backscatter from the surface is large compared to volumetric returns, the flow velocities at the surface will tend emphasize the total measured velocities in that specific bin. On extremely calm days, it may be the surface provides a very poor backscatter target strength. Wind driven effects could cause the top layer to have a different flow regime than the lower lying water column.

The data collected clearly illustrate one thing: regardless of whether the site is stratified or not, there is often a time-variable component present which will change the effective range of the system, day-to-day, if not even hour to hour. This necessitates a real-time data screening algorithm which is capable of detecting contamination from either the surface or the bottom to enable quantifiable quality checks on the profiles generated. In stratified environments where the speed of sound profile changes with depth, the variability appears greater due to fluctuating refraction effects.

II. DESCRIPTION OF EQUIPMENT

A. The Horizontal ADCP

The HADCP used in this project consists primarily of a 300kHz workhorse (more precisely, the carrier frequency is 307,200Hz) with specially modified firmware to enable custom transmission of bi-phase coded sequences along with the ability to store in flash memory (or directly read out along the serial link) the raw phase and magnitude pressure returns from each of the four receivers. The unit differs from a standard workhorse in that the geometry of the receivers consists of two sets of each of two beams stacked vertically. This means that beams 1 and 4 point to the left 20 degrees from the front of the unit, while beams 3 and 2 point to the right 20 degrees from the front of the unit. The vertically stacked beams provide a larger physical dimension in that direction with the corresponding smaller angular beam divergence along that direction as well. All four beams were fired in parallel upon transmission, while each of the four was operated independently while in the receive mode. Fig. 1 shows a photograph of the HADCP unit. Fig. 2 shows the theoretical beampattern expected when the two transducers are fired together upon transmit and used separately upon receive.

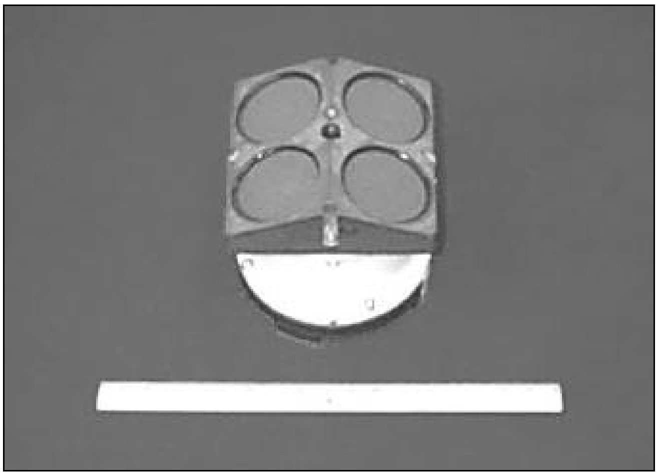

Fig. 1. Photograph of the RDI HADCP unit. A sixteen inch ruler is in the foreground.

B. The BBADCP reference unit

A standard 600kHz (more precisely 614,400Hz) RDI broad band ADCP (BBADCP) was used to collect the transect truthing data. This unit was mounted in the RDI engineering boat which has been modified to accept up to two units for testing.

C. The differential GPS unit

In addition to using the standard BBADCP reference unit, a DGPS unit was also employed during the transects with data collected. This consists of a Magnevox MX 300 DGPS High Precision Navigator with the differential corrections obtained from an LF unit receiving Coast Guard reference stations.

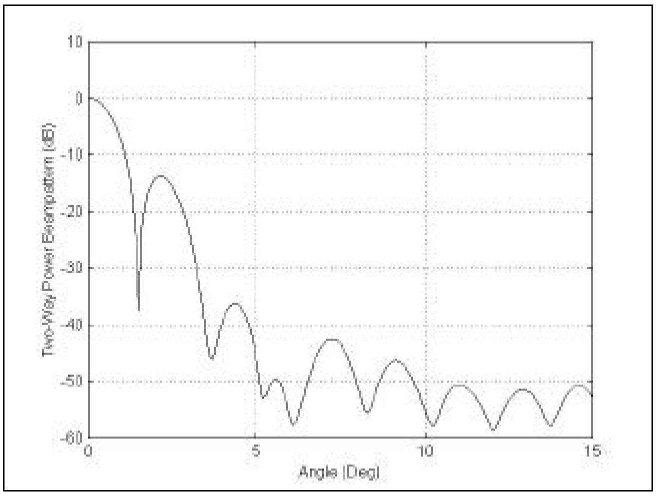

Fig. 2. Theoretical beampattern of the RDI HADCP unit.

D. Acoustic Velocity Meter (AVM) unit

These are operated by the US Geological Survey (USGS). They are essentially sound travel time devices mounted on pilings driven into the riverbed near each side of the river. The geometry of the pilings is such that they are at an angle with respect to the mean flow of the river. By measuring the sound travel time accurately, they are able to deduce the mean flow of the river.

III. Field Test Sites

Data were collected over a three day period from 26 October 1998 to 28 October 1998 at two locations on rivers near Sacramento, California. Site 1 was Jersey Point on the San Joaquin river, and site 2 is Walnut Grove “above” on the Sacramento river. The “above” refers to the fact that there is a significant bend in the river near this location and suitable sites existed both above the bend and after the bend. The USGS, and Mike Simpson, in particular was extremely helpful in assisting in the use of the pre-existing mounts and in the deployment and collection of both HADCP, Transect, and AVM data.

A variety of profiling bin sizes ranging from 1m to 4m were used. Additionally, a variety of runs using different correlation times ranging from 0.01s to 0.2s were also used. The unit was generally deployed between nine and ten feet in depth, although this was varied at site 2. The unit was also deployed typically in three different pitch angles: (i) flat, (ii) pointed down approximately 5 degrees, and (iii) pointed up approximately 5 degrees. This diversity allowed the identification of surface and bottom reflections at both sites. Because of the voluminous amount of data collected (between 60k and 130k bytes per ping) a variety of strategies were adopted. Some initial data was recorded to the internal 180MByte recorder pcmcia cards and then immediately downloaded to the PC for analysis later that day. The primary disadvantage of this procedure was the fact that considerable time was required, even at an RS-232 rate of 115k baud, to transfer the data. This did have the distinct advantage, however, that a quick, preliminary review of the progress of the data quality could be assessed in the field and corrections made, if required, the following day. This was followed for the first few files on the first day at site 1 as well as some of the files of site 2. The remainder of the data was stored on the cards and post-read after the conclusion of the experiment.

Fig. 3 shows a photograph of the transducer location used at site 1 – Jersey Point. Although difficult to see from this photograph, the far piling has two rails mounted on it running the length of the piling. The HADCP was mounted to a dolly with spring loaded wheels designed to mount onto the tracks. In this manner, the unit could be raised and lowered from the water. Once in the water the unit is firmly secured from random rotations or motions. A set of aluminum shims were used to enable the unit to be additionally tilted either towards the surface or the bottom. Fig. 4 shows the view from atop the transducer platform, looking across the river. The approximate distance to the shore is about 550m, while the depth of the river was about 15m. The Jersey Point location is interesting because it is tidally driven. It is far enough away from the ocean, however, so that it is primarily fresh water and does not have severe stratification problems. A 12-volt battery with a small inverter hooked to the HADCP and a laptop computer were housed in the small cabinet atop the transducer location. In addition to AVM data every 5 to 15 minutes, transects were also run using the RDI craft designed for this purpose. Differential GPS along with an RDI BBADCP 600kHz reference unit were used to collect numerous transects during the experiment. Fig. 5 shows the Walnut Grove site on the Sacramento river.

Fig. 3. Photograph of the HADCP transducer location for the Jersey Point site on the San Joaquin river.

Fig. 4. Photograph taken from the transducer location for the Jersey Point site looking across the San Joaquin river. The width of the river is approximately 550 meters.

Fig. 5. Photograph of the Walnut Grove site. The width of the river is approximately 100 meters.

IV. Results

A. Comparison of Currents to Transects

Comparisons between the HADCP horizontal current profiles, and a depth bin averaged transect profile which is categorized based on distance away from the transducer can be made. The distance the boat is from the HADCP may be computed by one of two methods (both were used to check the results): (i) integrate North and East bottom track velocities from the BBADCP and fluxgate compass starting at the HADCP location to obtain vector distance-made-good; or (ii) fix the DGPS latitude and longitude of the HADCP location and use the DGPS latitude and longitude data collected during the transect to compute a horizontal distance-made-good away from the unit. The x-y data from the HADCP must be rotated into the magnetic North-East frame used by Transect. By consideration of all the data collected at Jersey Point, the angle of rotation was found to be approximately 158.5 degrees and was fixed at this number for all of the analysis. Fig. 6 shows an example comparison of the North and East current profiles for the Jersey Point location as a function of horizontal distance across the river for a run using 4m bins and a transect conducted immediately before the collection of the data. A comparison of the data shows reasonably good correspondence, although it is possible that bottom contamination near the tip of the range is pulling the HADCP estimates down closer to zero velocity. An alternative explanation is that the two instruments are not measuring precisely the same vertical portion of the river.

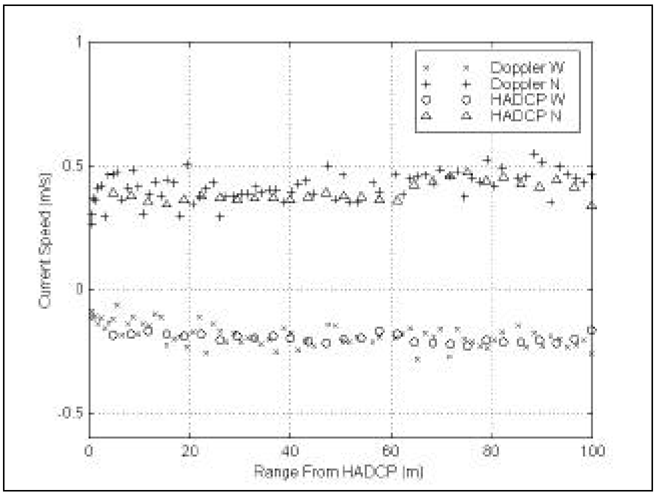

Fig. 6. Comparison of the HADCP Jersey Point data with a Transect taken using a 600kHz BBADCP and DGPS.

B. Comparison of Currents to AVM Data

The AVM measures the mean velocity across the entire river using travel time techniques. Naturally, when comparing with the HADCP which is capable of profiling only a portion of the river (about 100m) at Jersey Point, a calibration factor will need to be applied to the data to allow correspondence with the mean flow averaged over approximately 500m of the river. Because the site at Jersey Point is tidally driven, it has been noted by the USGS that the AVM data requires two calibration factors for discharge measurements, corresponding to the condition of inflow or outflow. Accordingly, the provision for two calibration factors for the HADCP was allowed. One was applied for negative velocities, while the other applied for positive velocities. Additionally a 15 minute delay to the HADCP data was found to be necessary. The origin of this delay is presently unclear. It is possible that changes in the mean flow occur near one bank first, then propagate across the river. There could also be some delay associated with the filtering process of the AVM data, although this has been investigated and appears unlikely. Fig. 7 shows the result of the longest, overnight run in which the HADCP collected data from about 5:44pm on 26 Oct 98 to 9:50am on 27 Oct 98. The correspondence is excellent between the two sets of data. Additional data from the AVM is shown before and after HADCP collection to illustrate the tidal nature of the site. It is highly desirable to collect more data of this type over a much longer period of time (three months or more) to see if the calibration factors continue to remain valid.

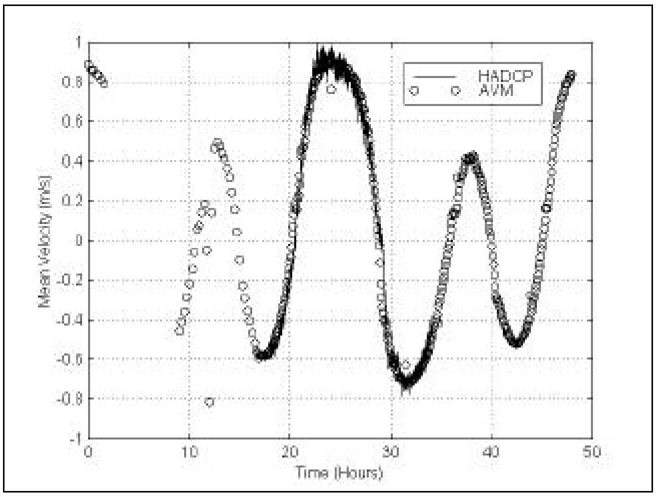

Fig. 7. Comparison of the calibrated HADCP Jersey Point overnight data with the AVM mean flow measurement.

V. Conclusion

The objective of this research is to develop a horizontal ADCP for mapping horizontal flow structure in channels, harbors, and ports. This would be useful in areas where time varying currents pose a threat to safe boat navigation. A real-time system would provide valuable feedback. The challenge for such a system is to measure flow even though the motionless bottom and or surface could contaminate the acoustic returns. A second application is the estimation of flow discharge in rivers and channels.

A modified 300kHz workhorse unit was used to collect and analyze field test data from a variety of sites. The unit is unique in that the four transducers are stacked two-by-two vertically. When deployed mid-depth in a river and pointed sideways, the HADCP determines the horizontal current flow profile in the river. The two transducers stacked vertically produces a narrower beam in that direction than a traditional unit. Special firmware was developed to enable a great variety of code sequence transmission patterns as well as the ability to collect raw pressure bits in time from each of the four receivers. This enabled a rich variety of detection algorithms to be investigated.

Data was collected at two river sites near Sacramento, California: Jersey Point on the San Joaquin and Walnut Grove on the Sacramento river. Jersey Point is interesting because the flow is tidally driven producing both positive and negative flow velocities. The Jersey Point location was a river approximately 550m wide by about 15m deep. This site yielded excellent data for surface and bottom contamination cases as well as clean water profiles to the range of the instrument (about 100m). Walnut Grove was shallower, about 100m in width, and due to an unfortunate tomography, yielded information primarily on the effects of side-lobe and main-lobe bottom contamination only. This would indicate that careful selection of the site, coupled with careful deployment geometry and considerations is vital to the success of the HADCP instrument.

Comparisons were made between the HADCP profiles and both transect profiles and AVM average flow velocities. In general, when the unit was situated in a geometry which primarily avoided the surface and the bottom, the unit worked well. This would indicate, that at least for some choices of river deployment locations, the HADCP is a viable means to derive horizontal current structure as a function of range from the instrument, as well as mean flow and estimates of discharge when suitably calibrated.

One of the important conclusions drawn from all sites is that the range of the system tends to vary even in locations which are not thought to be significantly stratified. This highlights the need for a real-time data quality assessment algorithm to detect the corruption caused from surface and bottom contaminations.

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