Sound Principles. Good Advice.

Application Note

Automated Quality Control in the SonTek® FlowTracker®

Abstract- The SonTek® FlowTracker® was introduced in 2001 with the intention of providing laboratory quality ADV® (acoustic Doppler velocimeter) velocity measurements in a format suitable for wading discharge measurements. Since that time, the FlowTracker has gained widespread support both in the U.S. and overseas as a modern alternative to conventional mechanical current meters. The original firmware algorithms inside the FlowTracker mimicked conventional practices and offered limited QA/QC criteria back to the user. In order to extend full advantage of the ADV technology and the FlowTracker's micro processing capabilities, extended features were added to the device in the form of a firmware and software release in the fall of 2006. These new features focus on automated quality assurance and quality control and take advantage of the extensive set of parameters available with FlowTracker data collection. An Automatic QC Test is conducted at the start of each measurement to verify all aspects of instrument operation; results are analyzed in real time and stored with each data file. User supplied data (measurement location, water depth) are monitored to look for possible data entry errors. Quality control parameters (including signal to noise ratio, standard error of velocity, flow angle, and section discharge) are analyzed with each velocity measurement. These parameters are compared to adaptive criteria that adjust with changing stream conditions; the operator is notified immediately of any suspect measurements. At the end of each measurement, the overall measurement uncertainty is calculated along with the contribution of different parameters (this indicates the primary sources of uncertainty). We will discuss the approach we have taken to implementing these features, how they should be interpreted by the user, and how it can result in a more robust and reliable discharge measurement.

I. BACKGROUND

The SonTek FlowTracker is an acoustic Doppler velocimeter (ADV)[1] designed for wading discharge measurements[2][3][4] following established methodology (including ISO[5] and U.S. Geological Survey standards). Since its 2001 introduction the FlowTracker has been adopted by a large number of agencies in the U.S. and abroad. A typical FlowTracker mounting, showing the probe and handheld controller on a top setting wading rod, is illustrated in Figure 1.

As with any instrument, using the proper technique is critical for data quality. If the FlowTracker can offer feedback to the user and detect potential problems before or as they occur, this can only improve the overall measurement process and resulting data quality. Potential problems may be related to measurement procedures, or to the velocity or discharge data collected with the FlowTracker. QA/QC procedures can be used to establish a long term basis to monitor data quality from site to site.

In addition to velocity the FlowTracker generates a number of other parameters that can be used to ensure the validity of the velocity measurement. These parameters reflect on the operation of the instrument and the measurement technique being used. The intelligent review and reporting of these QA/QC parameters has been named Smart QC. These new features should significantly improve the quality and reliability of data collected with the FlowTracker.

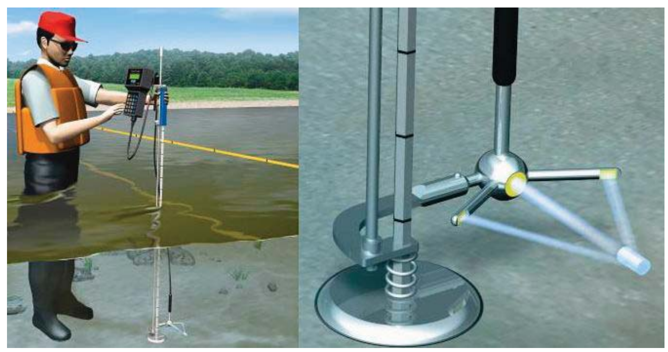

Figure 1 – SonTek FlowTracker on Top Setting Wading Rod

II. OVERVIEW

In a wading discharge measurement, velocity and depth measurements are made at a number of locations across the width of a river or other open channel. Following established methodology, these measurements are combined to compute the total discharge in the river. The Smart QC algorithms in the FlowTracker are designed specifically to work with discharge measurement procedures, although the routines are also applied to general purpose (non-discharge) velocity measurements as well.

The goal of Smart QC is to provide is the best overall discharge measurement possible, in the least amount of time. To do this the FlowTracker evaluates all data used to calculate discharge, verifying the integrity of each part as the measurement is made. These tests can be divided into the following areas.

- Verify the FlowTracker is working properly
- Check for errors is user supplied data
- Review QA/QC data for each velocity measurement
- Warn user of any suspect data, repeat or add measurements as appropriate
- Calculate overall discharge uncertainty

Some SmartQC features operate as data is being collected, others are performed after several data points, and some are done when a discharge measurement is completed.

III. VERIFYING INSTRUMENT OPERATION

To make a valid measurement, naturally the FlowTracker must be working properly. To check basic system operation at each measurement site, we have implemented the Auto QC Test. This is an automated version of the PC software BeamCheck (also called ADVCheck), which should be run once per week in the office as part of regular system testing.

The user is prompted to run the Auto QC Test at the start of each discharge measurement. The test is run directly from the FlowTracker handheld controller (without being connected to a PC). When prompted, the user places the FlowTracker probe in open, moving water (well away from any underwater obstacles), and presses a key to start the test. The system collects ~30 seconds of data and analyzes that data to verify all major aspects of system operation.

Data collected with the Auto QC Test is identical to data collected with the BeamCheck software; the tests results are recorded in the FlowTracker data file and displayed by the PC software. A sample output of the Auto QC Test is shown in Figure 2 (as it appears in the PC software output).

As with the BeamCheck software, the Auto QC Test shows a plot of signal strength from all beams versus time (distance) from the transducers. The Auto QC Test results are analyzed for four separate features, the same four items recommended for primary BeamCheck analysis (and described in detail in the FlowTracker manual).

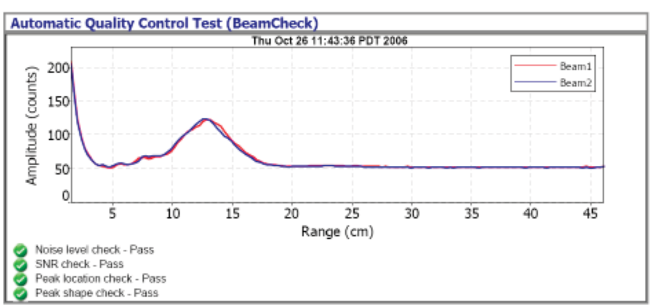

Figure 2 – Sample Auto QC Test Results

Noise level

- Is the system noise level within expected bounds?

SNR (signal to noise ratio)

- Is SNR sufficient for reliable operation?
- Are all beams seeing the same SNR?

Peak location

- Is the sampling volume peak in the expected location?
- Do all beams see the peak in the same location?

Peak shape

- Does the sampling volume peak show the expected smooth, bell shaped curve?

A warning is given if any tests results fail the expected criteria. If this occurs, reposition the probe (in case there was interference from an underwater obstacle) and repeat the test. If the warning persists, connect the FlowTracker to a PC and run the BeamCheck software for more detailed analysis; if necessary contact SonTek/YSI for more guidance on evaluating system operation.

IV. USER SUPPLIED DATA

During a discharge measurement, the operator inputs location and water depth for each station across the river. Location and depth are used to calculate area for each station; area is multiplied by velocity to give discharge. A typical discharge measurement might have 25 stations, so the operator enters many data points. Naturally errors in data entry occur, and if not detected they can significantly affect the final discharge calculation and the amount of time for the entire measurement process (if a measurement must be repeated).

Measurement stations are typically spaced evenly across the width of the river. During operation, the FlowTracker predicts the next station location based upon previous location values (assuming equal station spacing); if station spacing changes, the operator has to manually modify the predicted station location. The FlowTracker reviews input location data based upon the following criteria.

Station spacing

- Has the station spacing changed significantly?
- If so, this may indicate a data entry error.

Station order

- Is the new location out of order – such as between two existing stations or prior to the starting edge?
- Out of order stations are allowed (they will be sorted into the correct position for discharge calculations), but they must be confirmed by the operator.

In general, water depth should not change drastically between adjacent stations (a large change in depth might indicate that another station should be added between the two locations). To check for data entry errors, the FlowTracker compares all water depth values to water depth for adjacent station(s). The user is instantly warned of any large change in depth and prompted to verify the depth data.

The percentage of total discharge covered by any one station is also important. Most agencies have a policy that no individual station should include more than a certain percentage of the total discharge (this value varies from agency to agency, but 10% is typical). If a single station exceeds this value, an additional station should be added.

- If the user has provided a rated discharge value for the river, the percent of rated discharge is reviewed at the completion of each station.
- At the end of each measurement, all stations are reviewed to see if any station exceeds a certain percentage of the total measured discharge.
- When this occurs, the user is prompted to add additional stations to reduce the percentage of discharge.

V. MEASUREMENT QA/QC DATA

With each velocity measurement, the FlowTracker provides a variety of data in addition to mean velocity (which is used for the discharge calculation). These values can be used to verify the integrity of the velocity data and include the following.

- SNR (signal to noise ratio)
- Standard error of velocity (displayed as V)
- Number of spikes
- Flow angle
- Boundary QC

Each of these values, and the associated QA/QC criteria, is described in detail below. Including these automated tests with every data file ensures that FlowTracker data are archived with a strong indication that the instrument was functioning properly at the time of measurement, and that the environment is well suited for a FlowTracker measurement.

SNR

SNR is the single most important QA/QC value reported by the FlowTracker. The FlowTracker measures velocity by looking at the reflections of a pulse of sound from particles in the water; SNR is a measure of the strength of this reflection and the ability of the FlowTracker to distinguish the reflection from ambient electronic noise.

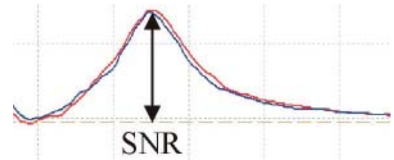

Figure 3 – SNR Peak on Auto QC Test Plot

When looking at Auto QC Test results (or a BeamCheck plot), SNR is the height of the bell curve that represents the sampling volume (Figure 3). SNR data for each FlowTracker velocity measurement is reviewed against a number of criteria to ensure reliable operation.

Minimum SNR

- Is SNR for all beams greater than 4 dB? This is the minimum level required for accurate velocity data.

Compare beam SNR

- Do all beams see that same SNR values?
- A large change between beams may indicate interference from an underwater obstacle or a problem with the FlowTracker probe.

SNR variation during the measurement

- SNR values are recorded once per second for each beam during the velocity measurement.
- Large variations in SNR during the measurement may indicated highly aerated water or interference from an underwater obstacle. Either of these can affect the reliability of velocity data.

Compare SNR from adjacent stations

- Is SNR at this station similar other stations in this file?
- Large changes in SNR between stations may indicate interference from an underwater obstacle.
- Changes in SNR may also be cause by local variations in the river and may not affect measurement quality.

Standard error of velocity

Standard error of velocity is a measure of the variation of velocity over the course of each measurement. Raw velocity data is recorded once per second; standard error is the standard deviation of the one second velocity data divided by the square root of the number of samples. By itself it estimates the uncertainty of an individual velocity measurement.

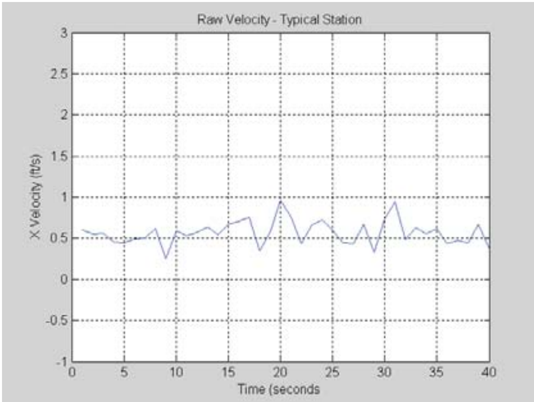

Figure 4 – Typical One Second FlowTracker Velocity Data

Standard error includes both instrument noise and turbulence in the measurement environment; turbulence is normally the largest component. A typical plot of raw velocity data is shown in Figure 4. In this example, the mean velocity is roughly (0.55 ft/s / 0.17 m/s) with modest variations around this mean. In highly aerated flow or if there is acoustic interference from an underwater obstacle, the variation of raw velocity data can increase dramatically. In this case, the standard error of velocity will also increase.

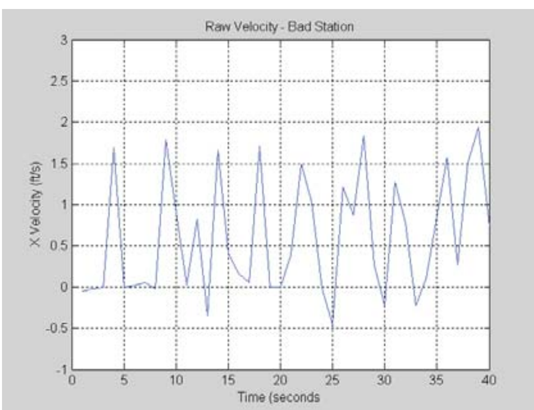

Figure 5 – One Second Velocity Data from Bad Station

Figure 5 shows raw FlowTracker velocity data from a station with interference from an underwater obstacle. While the mean velocity is (0.7 ft/s / 0.2 m/s), the one second velocity data varies from (0 – 1.5 ft/s / 0 – 0.5 m/s) with almost every sample. This results in a very high standard error of velocity that would trigger a warning to the operator.

The expected standard error of velocity will vary with the environment. A number of factors are taken into account when setting the standard error of velocity threshold value.

General minimum standard error

- Standard error values in good conditions are typically below (0.03 ft/s / 0.01 m/s).

High velocity

- Standard error of velocity will increase with velocity in the stream, so a minimum threshold of 5% of the stream velocity is used.

High turbulence

- Some streams are more turbulent that others and will therefore show higher standard error values.
- An adaptive threshold is used taking into account standard error values seen from all previous measurements in a given file.

Spikes

All acoustic systems see occasional spikes in velocity data; it is a normal part of operation and does not necessarily indicate a problem with the measurement. A FlowTracker might normally see one or two spikes over the course of a typical averaging time (although many measurements will not see any spikes).

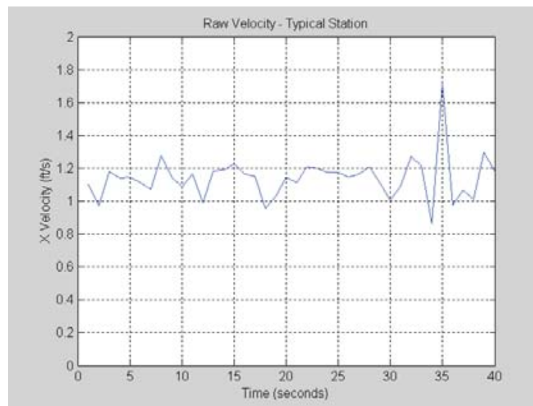

Figure 6 – Typical Raw Velocity Data with One Spike

Figure 6 shows the one second velocity data from a typical FlowTracker measurement. A single spike in velocity is seen at sample number 35. This spike is automatically filtered out of the mean velocity calculation, giving the true mean velocity (in this case about 1.1 ft/s / 0.35 m/s).

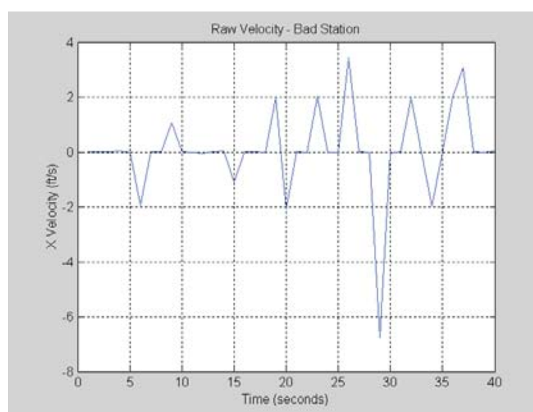

Figure 7 – Raw Velocity Data with Many Spikes

Figure 7 shows raw velocity data from a site with interference from an underwater obstacle; at this site the mean velocity is near 0 but there are a large number (8-10) of spikes over the course of the velocity measurement. This high number of spikes indicates a problem with the measurement; most likely the probe needs to be re-positioned and the measurement can be repeated. Any time the number of spikes is greater than 10% of the total number of samples, this very likely indicates a problem with the velocity measurement. In this case the probe position and environment should be evaluated carefully and the measurement should be repeated.

Flow Angle

The FlowTracker measures the true two or three dimensional velocity of the water. For discharge measurements, the X axis of the probe is kept perpendicular to the tag line used for probe position. By using only the X velocity for discharge, the FlowTracker correctly accounts for any variation in flow direction when making the discharge calculation. Using the two dimensional velocity data, the FlowTracker also calculates the true flow direction and reports this value as part of the QA/QC information.

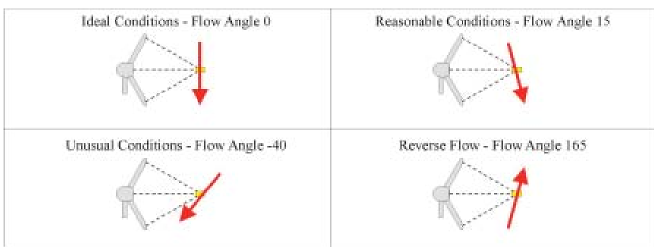

Figure 8 – FlowTracker Measured Flow Angle

At a good measurement site, the flow should be nearly perpendicular to the tag line at all stations, resulting in small measured flow angles from the FlowTracker (Figure 8). A large flow angle (typically considered greater than 20°) should be carefully reviewed. At some measurement sites, large flow angles are unavoidable and do not indicate a problem. In other cases, a large flow angle indicates either a problem with the measurement location or some type of interference with FlowTracker operation. If a large flow angle is reported but does not appear realistic, carefully evaluate the measurement location and repeat the measurement.

Boundary QC

The final QA/QC value used by the FlowTracker is also one of the most difficult to explain: the Boundary QC value. This is used to indicate possible acoustic interference from underwater obstacles. To understand this requires a brief explanation of pulse coherent processing, the technique the FlowTracker uses to measure the Doppler shift[2].

- For each velocity measurement, the FlowTracker sends two short pulses of sound.
- Comparing the phase of the return signal from the two pulses, and knowing the time between the pulses, we measure the Doppler shift (which represents the movement of particles in the sampling volume) very precisely.
- The maximum velocity that can be measured is a function of the time between the two pulses, called the pulse lag.
- The FlowTracker sends pulse pairs with a number of different lags for each measurement; this is done for the most accurate data possible over a wide range of velocities.

The FlowTracker measures velocity at a point nominally (10 cm / 4 in) from the tip of the probe; this location is called the sampling volume. If an underwater object is in this sampling volume, naturally it will cause interference with the measurement. With pulse coherent processing there is more than one acoustic pulse in the water at the same time; there is also potential from interference from the other acoustic pulse (i.e. reflections from the first pulse may be arriving when we are trying to measure the second pulse).

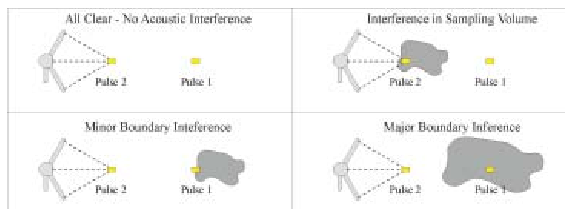

Figure 9 – Possible Boundary Interference Situations

Figure 9 illustrates a number of possible boundary interference scenarios. The relative locations of the two acoustic pulses in this figure are for illustration only; in real operation, a range of pulse spacing is used.

- Ideally, the sampling volume is free of any underwater obstacles and the first pulse is not hitting any obstacles when the second pulse is in the sampling volume case. In this situation, the FlowTracker can made velocity measurements without any adjustment (top left illustration in Figure 9).
- If an underwater obstacle is present in the sampling volume, the FlowTracker will always see interference and is unable to make accurate velocity measurements (top right illustration in Figure 9).
- If the first pulse is hitting an underwater obstacle at the same time the second pulse is in the sampling volume, then FlowTracker may see acoustic interference (bottom two illustrations in Figure 9).
    - It attempts to adapt its operation (by changing the distance between pulses) to avoid this interference.
    - If only minor adjustments are needed, the system can collect still collect high quality velocity data.
    - If major adjustments are needed, this may impact the ability to make a reliable velocity measurement (in particular to measure higher velocities). Ideally the probe should be re-positioned prior to the velocity measurement.

- It is still possible to make accurate measurements even when a boundary QC warning has been issued (i.e. if the probe cannot be re-positioned or if the warning persists), but data should be reviewed carefully.

VI. REVIEWING QA/QC DATA

The FlowTracker QA/QC procedures occur automatically over the course of the measurement. The exact timing of the test depends on the values being reviewed.

Data entry

- Location and depth data are reviewed when entered, and at the completion of the discharge measurement.

Boundary QC

- Boundary conditions are checked at the start of each velocity measurement; the user is warned of questionable conditions prior to making the measurement.

Measurement QA/QC values (SNR, standard error of velocity, number of spikes, and flow angle)

- These values are reviewed at the completion of each velocity measurement.
- All values are reviewed again at the end of the discharge measurement.

Station discharge

- If a rated discharge value has been input, station discharge is reviewed at the completion of each station (in comparison to the rated discharge value).
- In all cases, station discharge values are reviewed at the completion of the discharge measurement (in comparison to the measured total discharge value).

Whenever the operator sees a warning, the first step is to review the warning to see if it may reflect real conditions in the water. For example, if a high flow angle warning is issued, the operator should check if the water at that measurement location appears to be flowing with a large flow angle. If there is any question about the validity of the data, we recommend repeating the measurement after first carefully checking the probe location to be sure the sampling volume is well clear of any underwater obstacles. If the warning persists after repeated measurements, it may reflect real conditions in the water. In this case, the measurement can be accepted and the user can continue with the rest of the discharge stations; however, data should be carefully reviewed in post processing.

All criteria used for the automated QA/QC tests can be adjusted or disabled by the user (following instructions in the FlowTracker manual). In general, the default criteria should provide good performance with few false warnings.

VII. DISCHARGE UNCERTAINTY

The final piece of the automatic QA/QC procedures is to estimate the overall uncertainty of the discharge measurement. This estimates the very important question of how accurate is the measured discharge. The FlowTracker uses two different uncertainty calculations: the ISO method and one developed by researchers at the U.S. Geological Survey called the statistical method (both calculations are described in detail in a separate paper[6]).

Uncertainty results are shown both in firmware (on the FlowTracker LCD) and in the PC software. The uncertainty provides a quantitative addition to the subjective measurement quality estimate that many agencies report with each measurement. In addition to overall uncertainty, the FlowTracker displays the contribution of different factors to this uncertainty to help improve measurement quality in the future.

VIII. CONCLUSIONS

Regardless of the instrument, the quality of any field measurement relies heavily on the operator's technique. One of the best ways to improve measurement quality is to provide information and feedback that helps the operator improve their technique. The primary goal of the FlowTracker Smart QC algorithms is to provide a part of this feedback and improve the overall quality and reliability of discharge measurements in the field.

A secondary benefit is that it can save time in the field because it can catch potential problems early in the measurement process, and eliminate the need to repeat an entire discharge measurement or revisit a site. Because all of the QC data are recorded, there are also long term benefits to an agency's overall ability to look at improvements in data quality over time.

The tests and warnings used by the FlowTracker are intended to be largely self explanatory, and should with time improve the operator's knowledge of the instrument and hence quality of measurement.

IX. ACKNOWLEDGMENTS

The authors would like to thank Mike Rehmel and a number of others from the U.S. Geological Survey for their help in developing and evaluating the automatic QA/QC procedures for the FlowTracker.

X. REFERENCES

[1] SonTek and ADV are registered trademarks of SonTek/YSI, Inc., San Diego, CA, USA.

[2] Craig Huhta, *Handheld acoustic Doppler velocimeter (ADV) for water velocity surveys*. Hydraulic Measurements and Experimental Methods, EWRI and IAHR, 2002.

[3] Scott Morlock and Gary Fisher, *Hydroacoustic current meters for the measurements of discharge in shallow rivers and streams*. Hydraulic Measurements and Experimental

Methods, EWRI and IAHR, 2002.

[4] Gary Fisher and Scott Morlock, *Discharge measurements in shallow urban streams using a hydroacoustic current meter*. Hydraulic Measurements and Experimental Methods, EWRI and IAHR, 2002.

[5] ISO 748, *Hydrometry - Measurement of liquid flow in open channels using current meters or floats*.

[6] Craig Huhta and John Sloat, *Discharge Uncertainty Calculations Using a SonTek FlowTracker*, Australian Hydrographer's Association, 2006.

SonTek/YSI
9940 Summers Ridge Road
San Diego, CA 92121
Tel: +1 858 546 8327
Fax: +1 858 546 8150
Email: inquiry@sontek.com
Web: www.ysi.com