Highly Stable Long-Term Measurements of Height Differences with Digiquartz® Depth Sensors

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Summary

A novel system is described that can increase the accuracy of relative (differential) measurements of nearby absolute depth sensors over very long time intervals (years). This in-situ calibration/verification technique is particularly applicable to measurements of oceanic fault movements, subsidence phenomena, and platform leveling. The method is based on a temporary and periodic change of fluid density between adjacent depth sensors. A practical example is proposed using a local bubbler line between the sensors that is periodically filled with gas.

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Introduction

Digiquartz® Instruments are used in a broad range of oceanic and hydrologic applications (http://www.paroscientific.com/appnotes.htm#hydrology). Depth measurements vary from shallow water applications using gas-purge bubbler systems to the deepest ocean deployments using high-pressure depth sensors. These transducers employ resonant quartz crystal technology to achieve high accuracy, high resolution, insensitivity to environmental conditions, and low power consumption (http://www.paroscientific.com/qtechnology.htm). Measurement resolution better than 1 part per million of full scale can readily be achieved (e.g. better than 1 mm at 1000 meters depth). This capability is fully utilized in measurements of short-term phenomena such as tsunami detection (http://www.paroscientific.com/pdf/realtimetsunami.pdf). It would be desirable to develop a calibration technique whereby the long-term stability of differential pressure measurements approaches the inherent resolution of the Digiquartz® depth sensors (http://www.paroscientific.com/highres.htm).

Many applications involve measurements of relative depths in nearby locations such as in platform leveling, sea floor subsidence, and vertical changes in the sea floor during magma flow and plate movements. The physical measurement is the pressure difference (ΔP) of the vertical water column (h) between sensors (P_1, P_2).

$\Delta P = P_1 - P_2 = \rho g h$ where ρ is the density of water and g is local gravity.

For short time intervals, the relative pressure differences may equal the intrinsic resolution of each sensor. However, the long-term stability may vary among sensors from a few parts per million to 0.01 % of full scale per year. As a consequence, the uncertainty of these relative depth measurements over long time intervals can vary by two orders of magnitude, from millimeters to more than 10 centimeters.

It is highly desirable to improve the long-term accuracy of relative depth measurements of nearby pressure sensors. Since the absolute stability is a function of the full-scale range of the sensor, the lowest available range that meets the expected deployment depth should be selected. Other methods for improving the accuracy include using redundant sensors, matching sensors with similar characteristics, conditioning and monitoring before deployment, modeling long-term behavior, and calibration and subsequent correction for drift after retrieval. While these efforts have been helpful, the resulting uncertainties are still larger than the intrinsic measurement resolution.

A calibration method for sea bed mapping was recently developed that compares the in-situ depth sensors with a stable high-accuracy pressure transfer standard aboard an ROV (http://www.paroscientific.com/pdf/seabedmapping.pdf). The pressure standard is brought to a docking point near the depth sensor with a remotely operated underwater vehicle. The ROV then moves from sensor to sensor at least once with a repeat point at the first sensor to guarantee that the transfer standard did not shift during the operation. The uncertainty of the comparison is much better than the unchecked variations among sensors. It is mostly dominated by the measurement uncertainty of the process including the stability of the transfer standard during the hour-long activity, the accuracy of the docking procedure, and the thermal stability of the ROV/sensor system.

Proposed Method

A novel calibration method is proposed in which adjacent depth sensors are connected with a pressure line that is opened to the ocean in a manner that does not influence the normal operation of the sensors. Periodically, however, the pressure line can be switched to and filled from one side with a fluid (preferably a gas) of much lower density. The other end of the line is kept open and exposed to the normal absolute pressure of the ocean environment. This underwater system is analogous to the surface gas-purge bubbler techniques used in many hydrological applications (http://www.paroscientific.com/abbmk4.htm). The flow rate can be reduced to a minimum or the supply of gas may be closed off after purging and prior to making a comparative pressure measurement of the two (or more) depth sensors.

The principle of operation can be understood as the solution of two equations with two unknowns, namely the vertical height h(t) and the sensor drift e(t) that are both functions of time (t).

In normal operation with the sensor pressure line vented to the ocean, the pressure difference is

Seawater $\Delta P(t) = P_1 - P_2 = \rho_w\, g\, h(t) + e(t)$ where ρ_w = seawater density

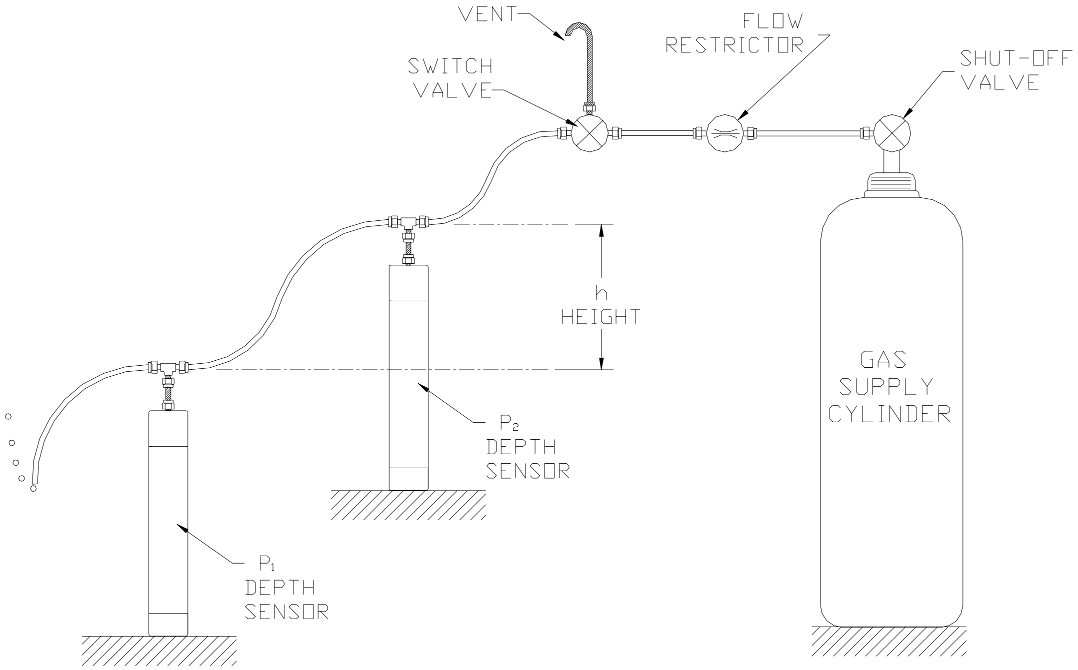
Immediately following a gas purge of the connecting pressure line, the pressure difference is

Gas $\Delta P(t) = P_1 - P_2 = \rho_g\, g\, h(t) + e(t)$ where ρ_g = gas density

After calibration at time t, exact values for the vertical height h(t) and sensor drift e(t) can be obtained from the two equations. From experience, e(t) varies very slowly and is nearly constant or changes at most linearly for a long time. For that reason, but depending on the need of the experimenter, the calibration could be performed only every few months, while the normal changes of the vertical height can be measured frequently. Between calibrations, the drift function can simply be extrapolated, and the collected data can be re-analyzed as new calibration information becomes available. From experience, the function e(t) is nearly linear, slowly changing, and continuous, and only a few points are needed to determine its shape. Typical modeling equations are straight-line fits, low-order polynomials, or power laws with few coefficients. A spline fit that matches the value and slope at each calibration point could be very effective to track the sensor changes over time.

Practical Considerations

The sketch below illustrates some of the basic elements of a bubbler system proposed for the in-situ calibration. The gas pressure of the supply tank must be greater than the water pressure, but gas quantity can be conserved for a very long time if the calibration is only performed at monthly or longer periods. At a minimum, a valve must be controlled between the tank gas and the normally open vent. In addition, some means should be provided to regulate the flow of the gas. The goal is to use the least amount of gas to fully purge the line and to shut it off during the actual measurement to avoid differential pressure from flow.



Bubbler systems are commonly used in shallow water and their operation is described on the Paroscientific website (http://www.paroscientific.com/waterlevel.htm). There are differences between existing bubbler systems and the proposed method. The most obvious difference to the land-based bubblers is that this entire system is submerged at high pressure, including the control valves. The operation of a surface bubbler system such as the Paroscientific PS-2 (http://www.paroscientific.com/pdf/ps2datasheet.pdf) is based on a continuous and very slow bubble rate through an orifice port. The hydrostatic pressure at the port is a function of water depth and is usually measured near the gas tank with a gas pressure sensor above the water. With this proposed method, the pressure sensors are submerged and connected hydraulically with an oil line to the seawater. The critical measurement is the differential pressure head between the sensors, not the absolute hydrostatic pressure at the orifice. In either case, the bubbler line must be fully purged and the diameter must be large enough to avoid any flow dependence to the measured differential pressure. A reasonable choice could be thick Nylon or rubber tubing with an inner diameter of 1/4th inch (6 mm). The port should be large enough to avoid fouling and should be oriented downward to avoid falling sediments. The occasional gas purge may actually be useful to keep the lines clear. Similar considerations should apply to the vent port. A gas purge line with an inner diameter of 6 mm (1/4th inch) extending between depth sensors separated by 100 meters would consume a gas-purge volume of only 0.003 cubic meters (0.1 cubic feet) for each calibration/verification cycle. A typical scuba-type tank with a capacity of 100 cubic feet can provide hundreds of calibration cycles over many years.

Some design work and experimental optimization of the fluid/gas interfaces may be necessary for optimal performance. The interfaces should be identical among sensors to eliminate common-mode errors. As shown in the sketch, an open interface between the gas and the sensor port may be the most practical. Under gravity, the fluid should be below the gas and the interface area should be horizontal. Line diameters should be large enough to eliminate meniscus effects and trapped gas bubbles. A “T” connection with internal diameter of 1/4th inch should suffice. Alternatively, a diaphragm or plastic baggie interface could be considered, which, however, pose different potential problems (loss of fluid, temperature sensitivity, trapped gas, etc.).

Operationally, the depth sensors can be used to enhance the accuracy of the process. For instance, it should be possible to monitor the purge and shut off the gas flow based on the measured depth information. The data acquisition system should be capable of synchronizing the pressure measurements of adjacent sensors to fully eliminate residual common mode errors such as fluctuations in overall pressure near the bubbler port. Furthermore, the accuracy of the calibration can easily be tested in-situ by repeated measurements. The goal is to repeat the calibration to within parts per million of sensor range, such that the long-term stability of differential pressure measurements approaches parts per million per year (e.g. better than a few millimeters per year at 1000 meter depths).