Volume measurement using 3D technology

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ABSTRACT

Large-scale manufacturing industries ranging from power industry to cement to steel, plastics and others must overcome challenges of accurately assessing and controlling inventory in order to successfully manage the entire production process. Hundreds of different kinds of storage bins and silos around the globe of different shapes and sizes store materials with widely varying basic characteristics – dielectric constants, particle size, particle type, chemical make-up of particles, and more. Conditions inside bins and silos are often harsh: they are dusty, impacted by extreme temperatures, and subject to anomalies of irregular surfaces and unbalanced filling and emptying.

In this paper we will introduce a technology which employs an array of low frequency transducers to measure and map the entire surface area, and a patented algorithm that processes the information to generate a 3-dimensional map. The technology enables to measure the volume and mass of materials in new applications that other technologies cannot reach. It enables measuring practically any kind of material stored in an almost unlimited variety of containers, including large open bins, bulk solid storage rooms and warehouses. It enables mapping loads that randomly form over time inside silos, and many other previously inaccessible applications.

Providing much greater accuracy in its measurements and significantly enhanced overall performance, the technology represents very attractive solutions to continuous level & volume measurement challenges. The technology translates into major cost savings and faster returns on investment, and allows managers to make informed decisions that go right to the bottom line throughout the entire supply chain

INTRODUCTION:

The technology relates to monitoring of inventory and to process measurement, and, more particularly, to a system and method for measuring the content of a bin. The monitoring of liquid inventory generally is straightforward. By contrast, the monitoring of bulk solid inventory that consists of particulates piled up inside a bin such as a silo often is very difficult. Examples of such bulk solid inventory include cement, coal, fly ash, etc. The measurement of the level of bulk materials inside a bin is a problem that has not yet been solved adequately. The conditions inside bins typically are unfavorable (dust, extreme temperatures, etc.) and the contents of the bulk material stored in the bins often do not have a flat surface and are not always isotropic. Other difficulties arise from the wide variety of bin shapes in use and from the explosive atmospheres inside some bins.

The scope of the term “bin” as used herein includes any storage container, for bulk particulate solids, whose structure defines an interior volume for receiving and storing the solids. Such a bin may be closed above, below and on all sides, as is the case when the bin is a silo, vessel or tank, or may be open above or on one or more sides. The example of a “bin” that is used in the detailed description of the present technology below is a silo; but it will be obvious to those skilled in the art how to apply the principles of the present technology to any type of bin.

Four principal methods are known for continuous measurement of the content of a bin such as a silo;

(1) An electromechanical (yo-yo) level sensor consists essentially of a weight at one end of a reel of tape. The weight is allowed to descend in the silo to the depth at which the top surface of the content is situated. When the weight settles on top of the content, the tension in the tape slackens. The weight then is retracted to the top set point. The height of the content is inferred from the time required to retract the weight or from the measured tape length. Mechanical devices such as yo-yo sensors are unreliable. They tend to get clogged by dust and to get stuck on obstacles such as pumps and rods inside the silos.

(2) Ultrasonic level sensors work on the principle of sound wave transmission and reception. High frequency sound waves from a transmitter are reflected by the top surface of the content to a receiver. The height of the content is inferred from the round-trip travel time. Such sensors have limited range and work poorly in the presence of dust. In addition, such devices need to be custom-designed for different types of silo.

(3) Radar level sensors work on the principle of electromagnetic wave transmission and reception. Electromagnetic waves from a transmitter are reflected by the top surface of the content to a receiver. The height of the content is inferred from the round-trip travel time. Such sensors are still based on a single continuous sample point and are therefore not accurate enough for bulk solid applications.

(4) Capacitance sensors measure the capacitance between two metallic rods or between a metallic rod and the ground. Because the silo content has a different dielectric constant than air, the capacitance changes according to the level of the top surface of the content between the two rods or between a rod and the ground. Such sensors tend to be inaccurate and are sensitive to humidity and to type of material stored in the silo.

All the prior art sensors discussed above are insensitive to the shape of the contents, and so are inaccurate in the presence of a common phenomenon called "coning" that occurs as bulk particulate solids are withdrawn via the base of a bin: an inverted conical hole, whose apex is directly above the point of withdrawal, tends to form in the bulk particulate solids. A similar phenomenon occurs as bulk particulate solids are added to a bin from the top: the solids tend to pile up in a cone whose apex is directly below the point of insertion of the solids. These sensors also work poorly in bins with complicated geometries and in the presence of obstacles.

There is thus a widely recognized need for, and it would be highly advantageous to have, a method and a technology of measuring the content of a bin such as a silo that would overcome the disadvantages of presently known methods as described above. In particular, it is not known in the prior art to map the upper surface of the bin contents in three dimensions.

METHODOLOGY/SUMMARY OF THE INNOVATIVE TECHNOLOGY – VOLUME MEASUREMENT

The technology employs a 2-dimensional array beam-former to send low frequency pulses and receive echoes of the pulses from the contents of the silo, bin or other container. The device's Digital Signal Processor samples and analyzes the received signals. From the estimated times of arrival and directions of received echoes, the processor generates a 3-dimensional image of the surface that can be displayed on a remote screen.

The 3DLevelScanner is unaffected by the type of materials being stored, avoiding the need for special calibration, or by environmental conditions, such as dust, filling “noise”, humidity, or temperature.

Three factors combine to make the technology an innovative one and the best-of-class solution for accurate measurement of bulk solids, particularly those in dusty environments:

1. Low frequency of transmitted signals (under 4 kHz)
2. A 3-antenna system that measures not only elapsed time between transmission and receipt of acoustic echoes but also the phase between the echoes
3. Proprietary algorithms enabling precise 3-D mapping of the contents inside the silo or storage bin

3DLevelScanner’s technology actually takes advantage of the large 70-degree beam angle (that results from working at a very low frequency), by using a three-antenna system with proprietary algorithms to add another important dimension, **direction**. The result is that every 5 seconds the 3DLevelScanner receives a matrix of x-y-z position coordinates that represent the echoes from the surface of the contents in the silo. Connecting these points together generates a highly accurate profile of the surface area, which in turn yields more precise measurement of the amount of materials being stored.

Method of Algorithm: How to find and detect the direction from which the echoes are coming from:

Step1: Every echo reflected back goes through classification algorithm.

The MUSIC (MUltiple SIgnal Clasification) algorithm: is a linear subspace algorithm that achieves performance close to Shanon limit with relatively low complexity cost. MUSIC estimates the frequency content of a signal or autocorrelation matrix using an Eigen space method. This method assumes that a signal, x(n), consists of p complex exponentials in the presence of Gaussian white noise. Given an $M \times M$ autocorrelation matrix, $\mathbf{R}_x$, if the Eigen values are sorted in decreasing order, the eigenvectors corresponding to the p largest Eigen values spanning the signal subspace. Note that for M = p + 1, MUSIC is identical to Pisarenko's method. The general idea is to use averaging to improve the performance of the Pisarenko's estimator. The frequency estimation function for MUSIC is

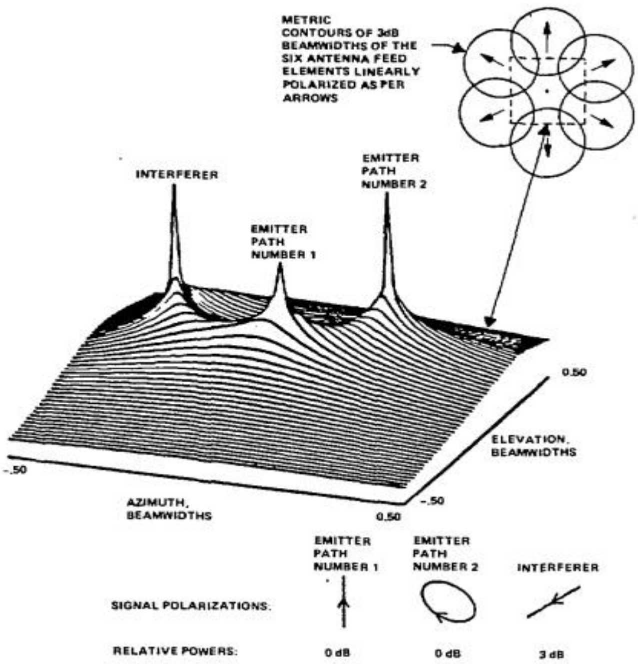
$$\hat{P}_{MU}(e^{j\omega}) = \frac{1}{\sum_{i=p+1}^{M} |\mathbf{e}^H \mathbf{v}_i|^2},$$

Where $\mathbf{v}_i$ are the noise eigenvectors and

$$e = \begin{bmatrix} 1 & e^{j\omega} & e^{j2\omega} & \cdots & e^{j(M-1)\omega} \end{bmatrix}^T.$$

Example of Music algorithm result with 2- dimensional array

1.



The algorithm records the exact time that every pulse is transmitted and the exact time every adjacent echo is received. The difference between these times is the time of flight of signal. The distance is the time of flight multiplayer by half the propagation speed (half because the signal travels forth and back).
The Speed of sound is given by

$$331.3\sqrt{1+\frac{T^{\circ}}{273.15}}$$

T is the measured temperature in Celsius.

For every direction of echo there is a specific set of relative phases induced on the scanner array. However there are some directions that create the same phases on the array even though the directions are not the same.
That effect can be avoided if the spacing between array elements is not more than half wavelength.

Step 2: Angle Calculation

When the spacing between array elements is larger than half wave length there are some different pairs of angles (θ1,φ1) and (θ2,φ2) that cannot be distinguished physically by the array. The smallest angle θ0, such that for every pair of spherical angles that fulfill θ1<= θ0 and Θ2<= θ0, the directions (θ1,φ1) and (θ2,φ2) induce different relative phases on the array (thus every two directions with smaller θ can be distinguished) is the maximal angle at which the array can figure direction without aliasing mistake. In triangular array this angle is given by:

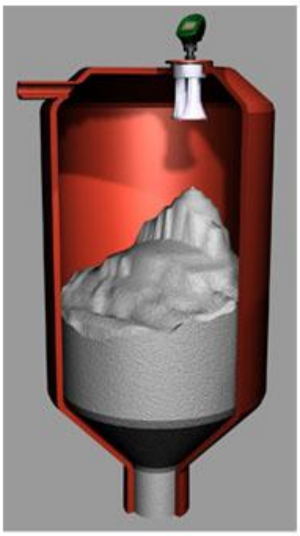
$$\theta_0 = a\sin\left(\frac{C}{\sqrt{3}\cdot f\cdot D}\right)$$

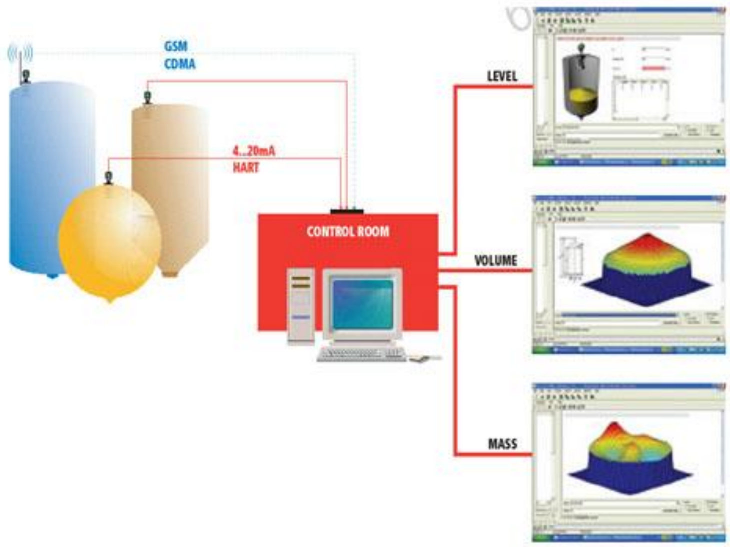
Where:
D is the spacing between antenna elements.
C the propagation speed
F pulse carrier frequenc

RESULTS

Using the described technology results:

(1) In the ability to profile bulk solid materials in silos such as the below examples:





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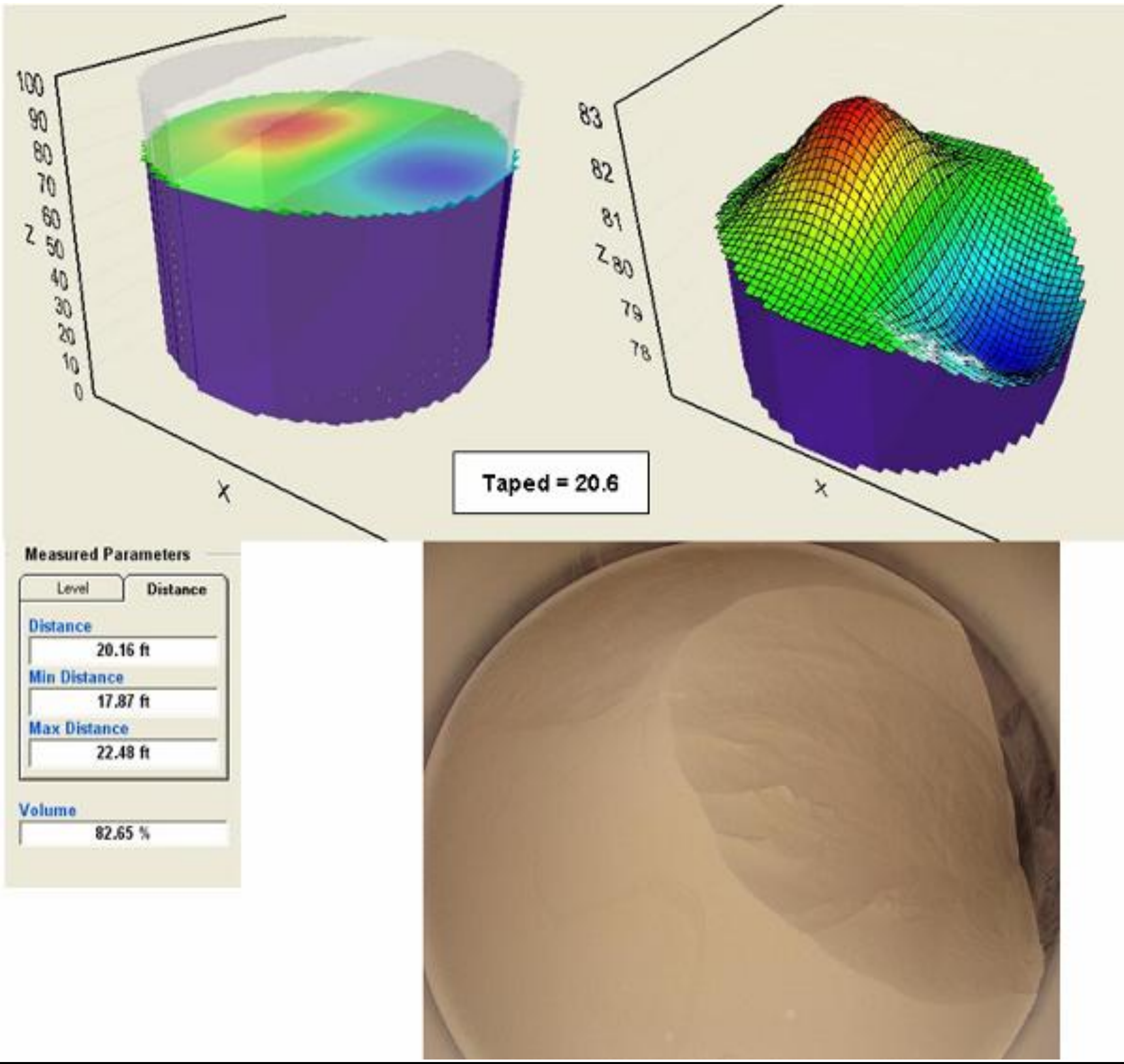
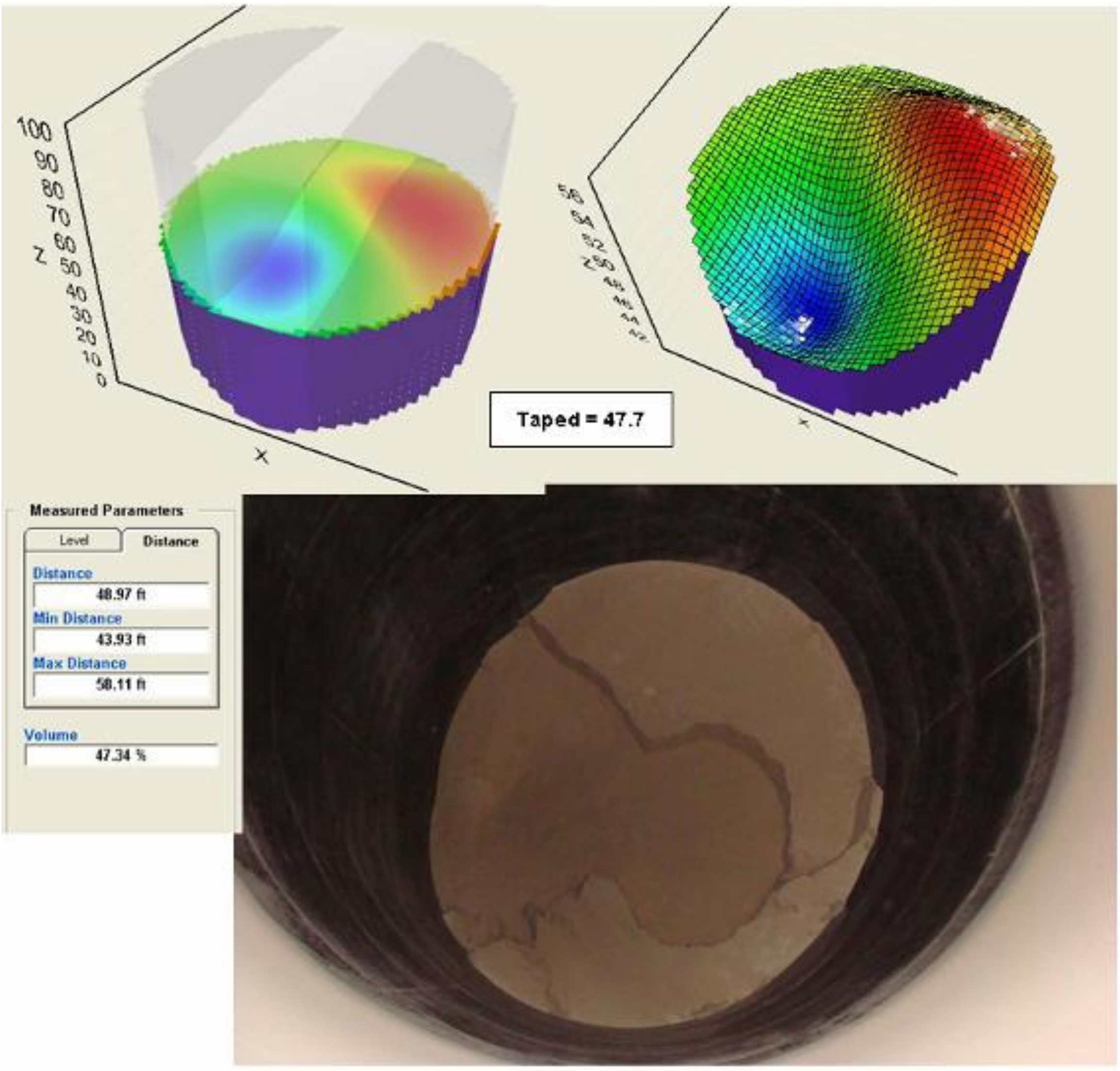
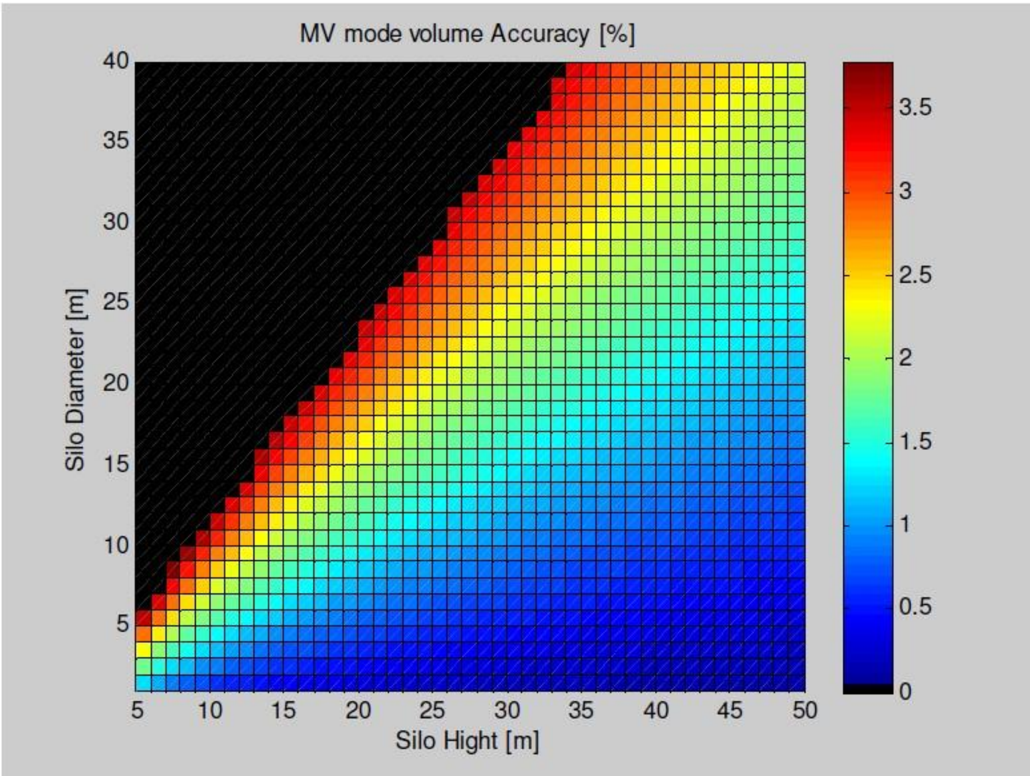

100
90
80
70
60
Z 50
40
30
20
10
0
X
83
82
81
Z 80
79
78
X
Taped = 20.6
Measured Parameters
Level
Distance
Distance
20.16 ft
Min Distance
17.87 ft
Max Distance
22.48 ft
Volume
82.65 %



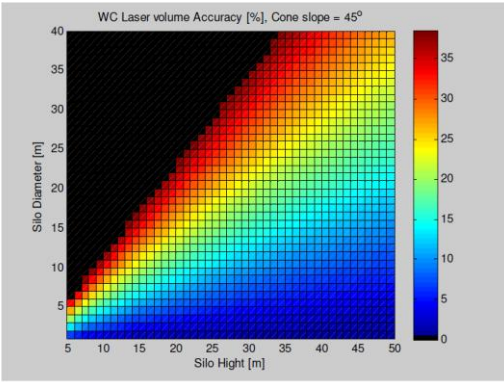
(2) The ability to reach unprecedented volume accuracy. The accuracy reached with the described technology:

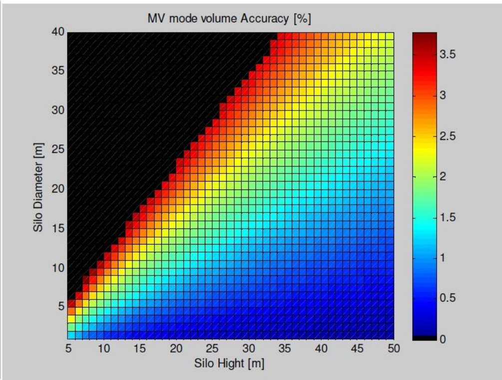


<u>Example</u>:
(1) In a 25 meters high silo and 15 meters wide, it is possible to receive volume accuracy of 1.5% - 2%.
(2) In a 25 meters high silo and 10 meters wide, it is possible to receive volume accuracy of 1%.

Conclusion

The results show a great improvement in the accuracy of measurement in bulk solid applications





Comparing today's technologies with the described technology shows an improvement in the volume accuracy by an order of magnitude.

In other words, in applications where the described technology would provide 1% accuracy, an existing technology (yo-yo, ultrasonic, radar) would give 10% accuracy.

Therefore, it is advisable for customers from a variety of industries (steel, power, cement, food, chemicals) who wish to asses more accurately the amount of materials they have in their silos for inventory purposes and optimization of manufacturing process to use the suggested technology.

Providing much greater accuracy in its measurements and significantly enhanced overall performance, the technology represents a revolution to continuous level & volume measurement challenges. This translates into major cost savings and faster returns on investment, and allows managers to make informed decisions that go right to the bottom line throughout the entire supply chain of their plant.