Electrical Capacitance Tomography system for determination of liquids in tanks rockets and satellites.

Zbigniew Gut, Piotr Wolanski
Institute of Heat Engineering, Warsaw University of Technology
Nowowiejska St. 21/25, 00-665 Warsaw, POLAND
e-mail: zgut@itc.pw.edu.pl

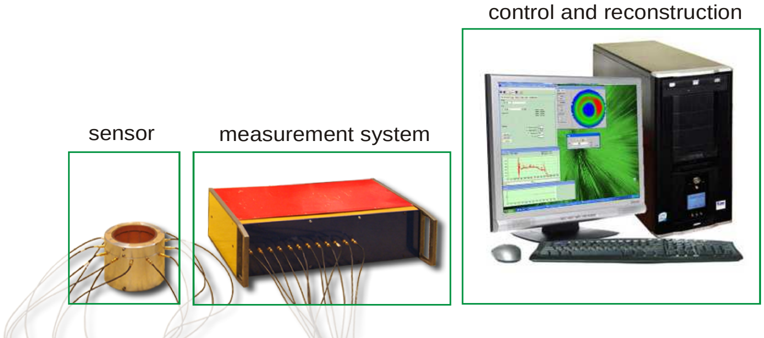
Abstract

The lack of gravity in the space environment makes it challenging to measure the amount of liquid propellant remaining in storage tanks. The main problem is the chaotic motion of fuel volume in the tanks due to no gravitational force. This chaotic motion causes a problems for the fuel system with diagnosing the accurate amount of fuel in the tank. There are several methods for determining liquid level in a tank while it is in low gravity. The most popular are: Pressure-Volume-Temperature Method (PVT Method), Optical Mass Gauging (OMG), Radio Frequency Mass Gauging (RFMG).

Each of methods have advantages and disadvantages, as well as varying feasibility for space flight applications. Many of these methods are not suitable for low gravity environments simply because they rely on gravitational forces to maintain a uniform distribution in the substance being gauged. In addition, some techniques capable of liquid or vapor mass gauging are not adequate for solid mass gauging due to their inability to discriminate between the presence of each form. To succeed in properly measuring the amount of fuel present in a tank that is exposed to a variable gravity environment, a technique must be reliable independent of fluctuations in gravitational forces, changes in mass distribution and changes in properties, which may be associated with changes of state or compressibility. New and more accurate methods of measurement are being continually searched for. One of the interesting solutions is using Electrical Capacitance Tomography (ECT) for the determination of liquids in tanks rockets and satellites.

ECT is a measurement technique that reconstructs dielectric constant distribution in an object by measuring the capacitances between the electrode pairs, which are mounted around the object. A typical application is real time monitoring of multi-component flows within pipelines. Specific applications where ECT has been successfully exploited include solid-gas and liquid-gas systems, such as fluidized beds, pneumatic conveying and multi-phase flow. In principle, ECT is used to investigate and monitor any process where materials are non-conducting, and the other phases and components have differing values of permittivity.

A typical ECT system has three main units: a sensor, a measurement system and a computer.

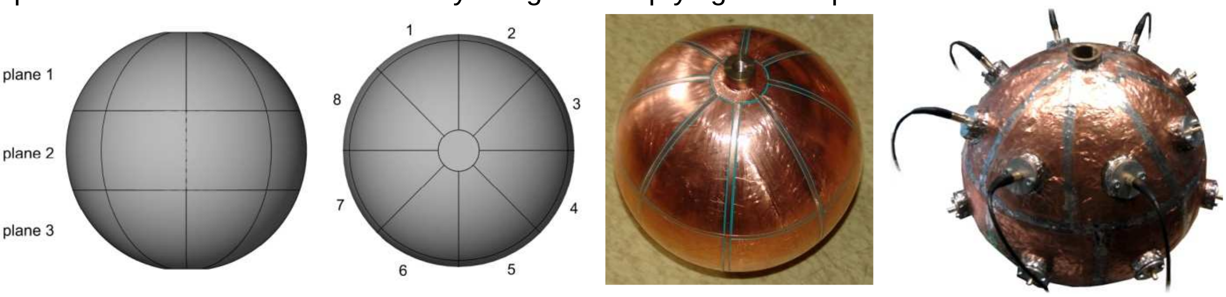


Schematic of the Electrical Capacitance Tomography system

The sensor consists of a set of electrodes symmetrically mounted outside measurement space. The sensing electronics measure the capacitances for all possible electrode combinations, when the electrode sizes and location are fixed, depending only on the permittivity distribution inside the ECT sensor head. The computer system has two major functions. Firstly, it controls the measurement operations performed by the sensing electronics, and secondly, it uses the measurement data to reconstruct tomographic images.

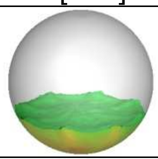
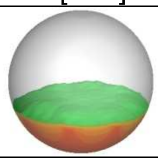
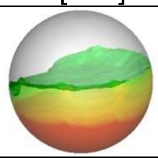
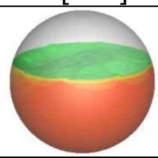
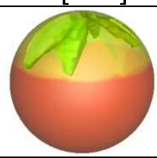
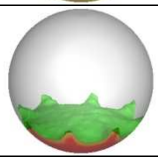
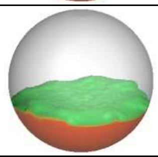
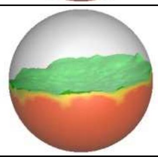
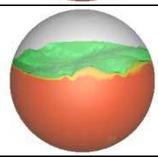
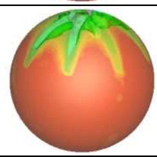
ECT images from capacitance measurements are generated using the Linear Back-Projection (LBP) algorithm. This algorithm is simple, fast and ideal for online reconstruction, but produces relatively low-accuracy images. For improving the accuracy of LBP images the iterative image computation methods are used. The most widely used iterative method to solve the problem in ECT is the Landweber technique, also called Iterative Linear Back Projection (ILBP).

The spherical tank is the most common satellite pressure vessel configuration. Thousands of spherical tanks have flown since the inception of the space age. Spherical geometry offers the best pressure performance, therefore, it provides the most mass-efficient pressure vessel design. In this work, a new 24-electrode capacitance sensor has been developed. The electrodes have been mounted on a non-conducting plastic sphere with 217.0 [mm] in diameter, which have been arranged in three planes where each planes consist of 8 electrodes. The total volume of sphere is V_{sphere}=5.34 [dm^3]. The sensor includes radial and axial guard electrodes, which are used to reduce the external coupling between the electrodes and to achieve improved quality of measurements. Size of the electrodes was chosen so that the area of each is similar. Two holes were made in the lower and upper spheres. These holes allow for easy filling and emptying of the sphere.

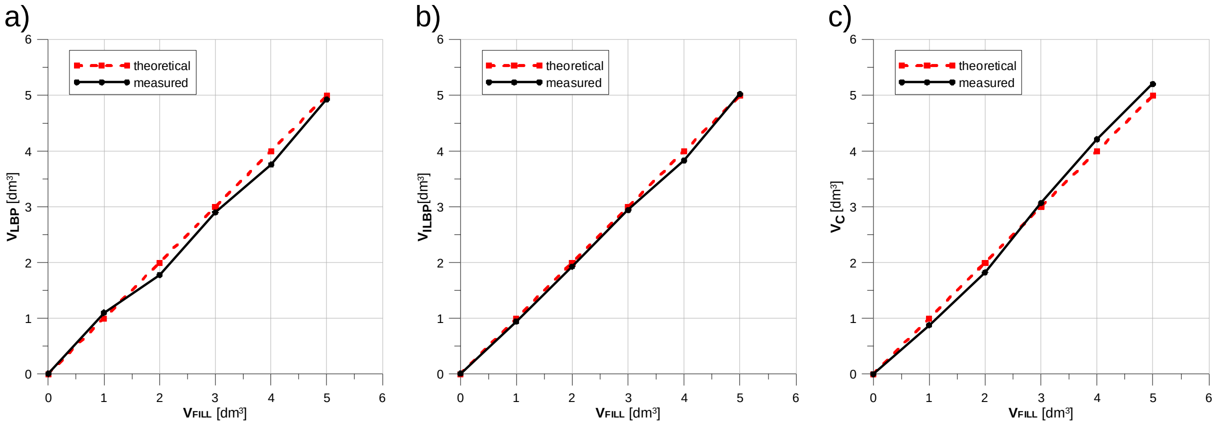


View of spherical capacitance sensor.

Research was divided into two stages. The first stage of research was carried out to determine how much fluid has been added when the tank stayed at rest. After entering a precisely defined dose of sand into the tank, a measurement system based on recorded data again determined the contents of the tank. Three methods were used to determine the content of the sphere. The first method uses the calculated values of normalized dielectric permittivity, obtained using the LBP algorithm (V_{LBP}). The second method uses a normalized value of dielectric permittivity obtained using the algorithm ILBP (V_{ILBP}). The last method is based on normalized values capacitance between electrodes (V_c).

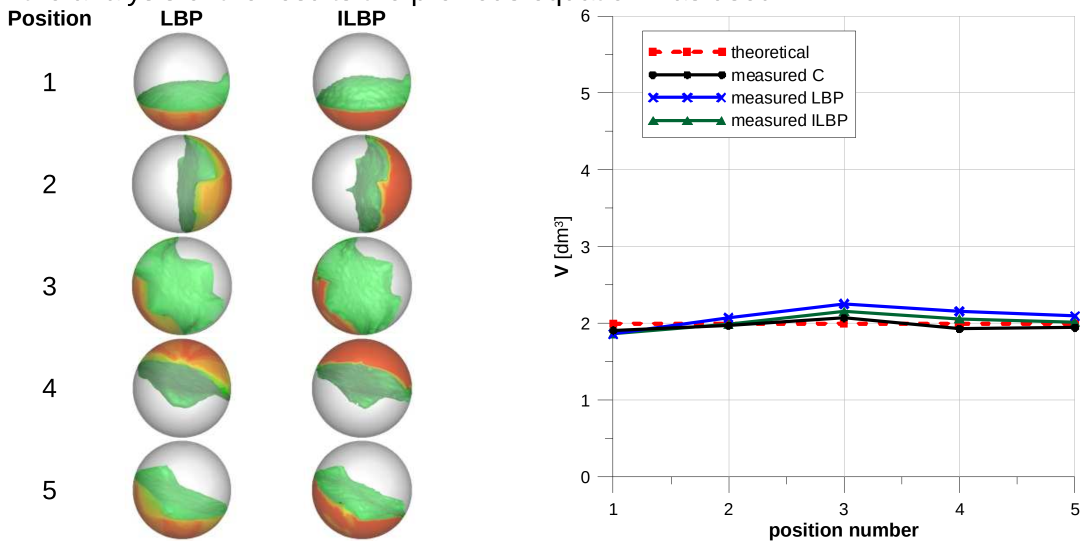
	1 [dm^3]	2 [dm^3]	3 [dm^3]	4 [dm^3]	5 [dm^3]
LBP					
ILBP					

Reconstructed images for different contents of the tank



Variation of tank contents for different methods a) LBP, b)ILBP, c) Cm.

The next phase of the study was to determine the level in the tank for different sensor positions. In this way, a different position of the tank was simulated depending on the position of the satellite in space. Due to the fact that the shape of the electrodes is irregular, changing the position of the tank will enable to estimate the impact of distribution of the material inside the tank to the accuracy of the reconstruction and fuel content. The reconstruction was made for four tank contents 1, 2, 3, 4 [dm3] and for a few tank positions. In the analysis of the results the previous equation was used.



Reconstructed images for 2 [dm^3] tank contents

In this work, results show that the ECT system is an interesting solution that may be used in monitoring systems of fuel tanks of satellites. We can see that the relative error is less than 10% when the content of the sphere was determined with the help of normalized values of dielectric permittivity obtained using the ILBP algorithm. Measurement data collected allowed not only to reconstruct the changes taking place inside the tank, but also allowed us to determine the contents of the tank. In future work, an improved ECT system will be developed to improve the resolution, and to present the images of the contents tank in real time. The proposed technique will be tested in low gravity environments by using a microgravity lift. It is believed that the ECT system holds significant promise for the future of detecting distribution and determining the amount of fluid in tanks rockets and satellites.