Inertia Sensor Detecting Materials using Electromagnetic Signals

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Abstract: There are many commercial sensors that use inertia systems and others that use electromagnetic systems. Until now, none of the existing sensors combines a circular inertia movement with the simultaneous transmission of electromagnetic radiation in the band of very low (VLF) and ultra low (ULF) frequencies. The aim of this paper is to show the design of such a sensor, that contains an electromagnetic signal generator and to observe and monitor its movement on a free rotating inclined platform. An accurate positioning and monitoring system is used in order to measure the velocity and acceleration at every position on its movement. It is a novel system that is already in use in material identification and localization. It is indubitably working and exports excellent results, although we are not still familiar with the laws of physics that determine the specific phenomenon. Until this point the sensor is used to identify only a limited number of materials. In the future it would be ideal to use it for more materials, find their frequencies and create a library that contains many materials and different kind of substances.

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1. Introduction

We live in a world that almost everything is controlled and sensed by sensors. The importance of the sensors for mankind is obvious. The first sensors appeared with the existence of the living creatures and they are their organs. Eyes and ears are typical examples. The first detect electromagnetic radiation, while the second detect sound. Later, man realized that he needed measuring instruments in order to solve everyday life problems, so he started creating sensors. The first sensors were mechanical, such as a thermometer. The rise of electricity led to the construction of electrical sensors. The evolution of semiconductors had as result the creation of new advanced sensors and digital measuring devices.

A sensor is a devise that detects a physical quantity and produces a countable signal. Usually modern sensors are devices that detect an external signal and respond to it with an electrical signal and they ensure that measurement data are transmitted faster and more accurate.

One of the classifications of sensors, is active-passive. The next classification is based on the kind of the materials the sensor detects, for example Electric, Biological, Chemical, Radioactive, etc. Another type of sensors are Analog and Digital Sensors. The final classification is based on the phenomenon that occurs, i.e. Photoelectric, Thermoelectric, Electrochemical, Electromagnetic, etc.

Some types of sensors are accelerometer, IR sensor, temperature sensor, pressure sensor, frequency sensor, gyroscope and many others. There are inertia sensors, such as gyroscope, and there are electromagnetic sensors such as accelerometer.

A unique sensor that combines the movement of an inertia system with the transmission of very low (VLF) and ultra low (ULF) electromagnetic frequencies is described below.[1], [2].

2. System and Circumferential (Apparatus)

An inertia system [3], [4] is on a circular motion path. The inertia system has a telescopic antenna and circuitry to bring signal to the antenna. Under some circumstances a force is exerted on the antenna of the inertia system that alters its expected motion. It has been observed that this force appears when specific material is located towards the direction pointed by the antenna. The antenna has emitted appropriate signal for the specific material.

This paper shows how the inertia system is designed and how it is operated. Then the Electronic Circuitry that is generating the signals on the antenna will be analyzed. Also, the circuitry on the inertia system, used to detect the force that is exerted on the inertia system at the presence of the material, is described. The method how the appropriate signals are found for each specific material is presented. Some parameters that affect the force will be analyzed

2.1. Inertia System Design and Operation

An inertia systems on circular motion is designed and operated that consists of four Units: (1) An Electronic Box containing: (a) a Signal Generator System, producing electromagnetic signals, and (b) a force detection circuitry, (2) a Telescopic Antenna where the signals are emitted from, (3) a perpendicular Axial fixed underneath the generator box around which the circular motion will take place and (4) a Base through which the inertia system is able to rotate around its Axial. **Fig.1 (a)**, **(b)** shows the System. By “x” is marked the Center of Mass of Units 1&2.

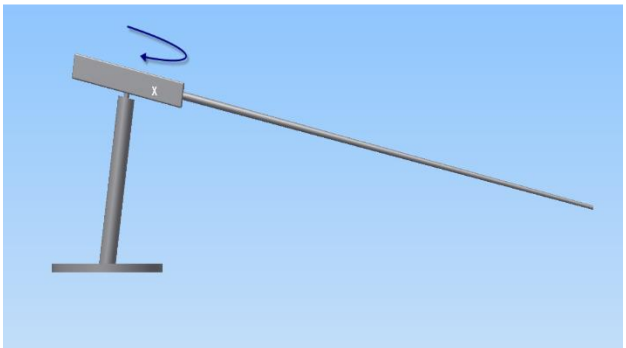


Fig.1 (a) The inertia system with its four units: Electronic Box, Telescopic Antenna, Perpendicular Axial and Base[5]

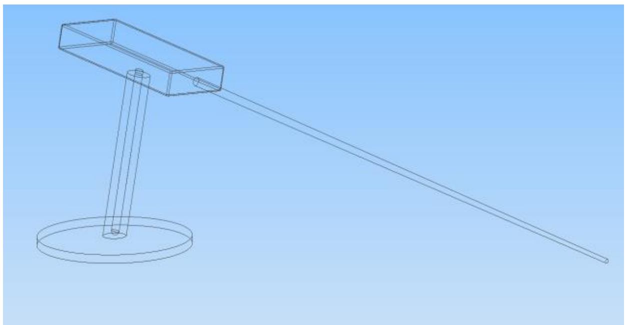


Fig.1 (b) The outline figure of the inertia system

The inertia system consists of 2 pieces: Piece 1 is the Electronics box with the antenna attached on it, and the perpendicular axial fixed underneath the generator box. Piece 2 is the cylindrical base with can hold the generator and antenna. Pieces 1 and 2 of the inertia systems can be viewed in **Fig.2**.

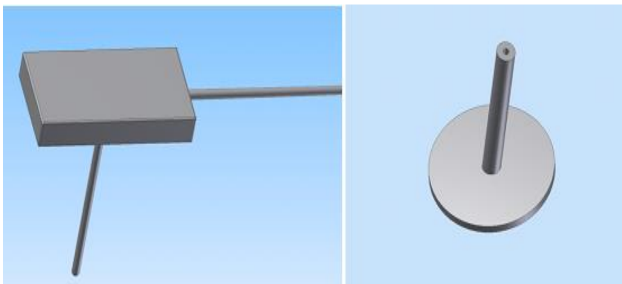


Fig.2[5]

The Base is tilted from vertical position. The system resting position is as shown on **Fig.3**.

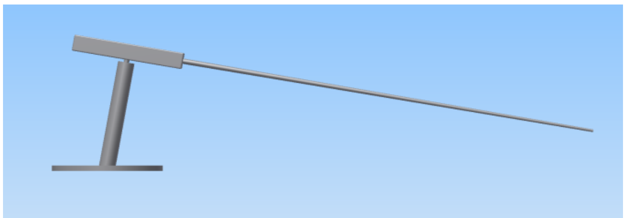


Fig.3 Resting position of the system

An initial position is given to the system. Then the system will start its movement. In the following **Fig.4**, the series of frames from 1-11 show the movement followed by the inertia system. Frame 1 shows the original position which is the initial condition of the system. The System is brought to initial position, Frame 1, and it is released to start its motion. Frames 1-11 show one oscillation.

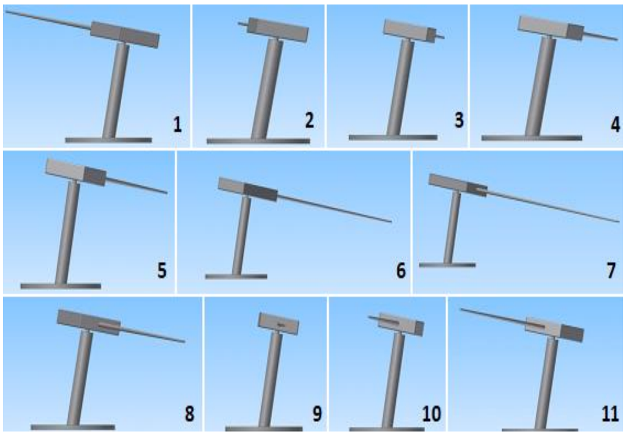


Fig.4

The weight W of Units 1&2, of Piece 1, is causing a torque that makes the inertia system to rotate on a damped oscillation around its axial. The Weight component on the direction of movement is Wt(t). Another force when the movement starts, is the friction T_f. The Inertia system follows a movement based on the application of these forces. The motion is described by angular velocity ω(t).

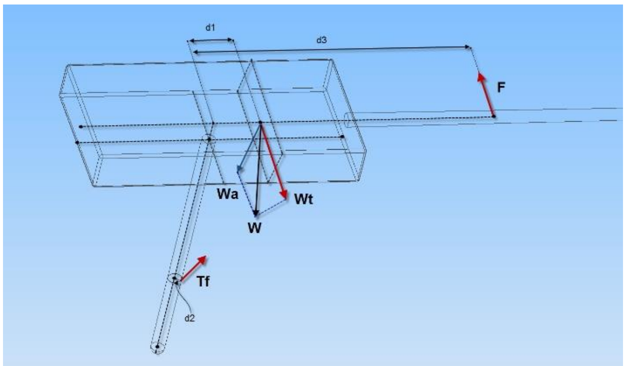


Fig. 5 Diagram that shows the forces on the system

On the antenna of the inertia system a signal is applied by the Generator Circuitry. Different signals may be applied on the antenna according to the type of material that will need to be detected and will be affecting the movement. When a material is located in a direction headed by the antenna, only then an extra force F is excreted on the antenna of the inertia system. This force F is opposing the movement. **Fig. 5** shows the forces on the system.

Then, total torque is calculated by the following equation:

$$\tau_{tot}(t) = d_1 \times W_t(t) - d_2 \times T_f(t) - d_3 \times F(t)$$

Fig.6 shows the forces exerted on the inertia system that affect its motion and the angular velocity ω(t) that the system is rotating around the axial. If ω(t) becomes zero before the end of the expected motion (frame 11) then this suggests the presence of an extra force exerted on the inertia system. The angular velocity ω(t) cannot become zero when the system starts its motion on the downward path (Frame 1-6). This is because the friction is small and the force F(t) is small too, compared to the weight.

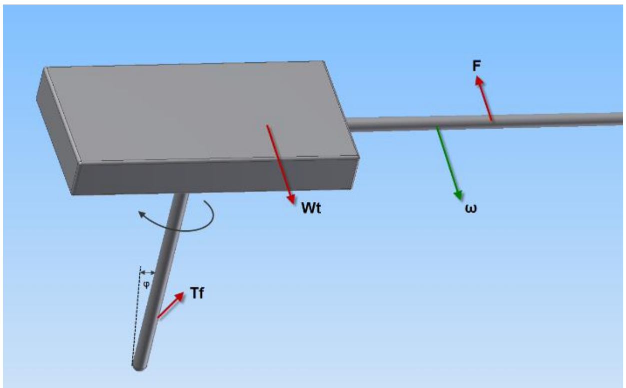


Fig.6

On the other hand, on the upwards path (Frame 7-11), all the forces act in the same direction opposing the movement ω(t), as shown in **Fig.7**. If the system stops before Frame 11 this suggests the presence of an extra force. The larger the force F the sooner the movement will stop. The following video shows the movement of the inertia system.

https://youtu.be/tcGJNDHG6AI

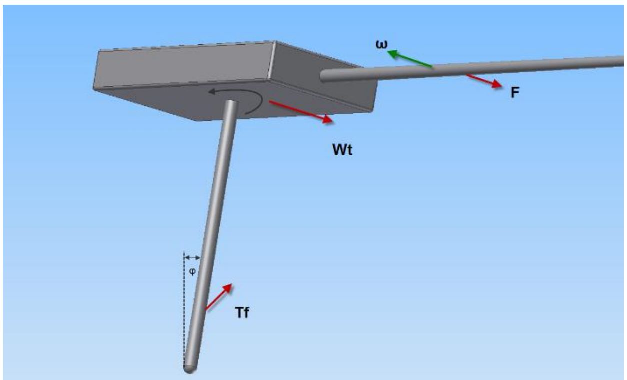


Fig.7

2.2 Electronic Circuitry

In this section, the electronics in the box of the inertia system are analyzed. The signal generator and the force detection circuitry have the electronics schematic diagram in the **Fig.8** bellow.

2.2.1 The Signal Generator circuitry

The Micro Computer Unit MCU1 processor receives commands from the user through a keyboard while the user can see and select from the display. In the MCU1 memory, information is stored about the signals that need to be produced for the different materials to be detected. The frequencies of the signals are from 1-100KHz. The signal amplitude is from 1-30V pp. A 3.3V lithium battery of 2700 mAh is used and powers up the system for about 10 hours. The system display remains powered on only while the user is changing the settings through the keyboard, so no considerable amount of power is consumed on the display. After MCU1 receives command from the user for the type of material to be searched, the MCU1 gives commands to the DDS to produce the signal for the selected material, with great accuracy of 0.001Hz. The output of the DDS is amplified and then put on the antenna. The user can select the amplitude of the output signal.

2.2.2 The Force detection circuitry

A vertical-axis accelerometer is used as a vibration sensor. It has been observed that: when the Force F is exerted on the system, as a result of the presence of material in the direction headed by the antenna, the inertia system mechanically vibrates with characteristic frequency. The signal of the accelerometer is conditioned and then entered into MCU2 to be processed. In the MCU2 an FFT algorithm is running to calculate the vibration frequencies.

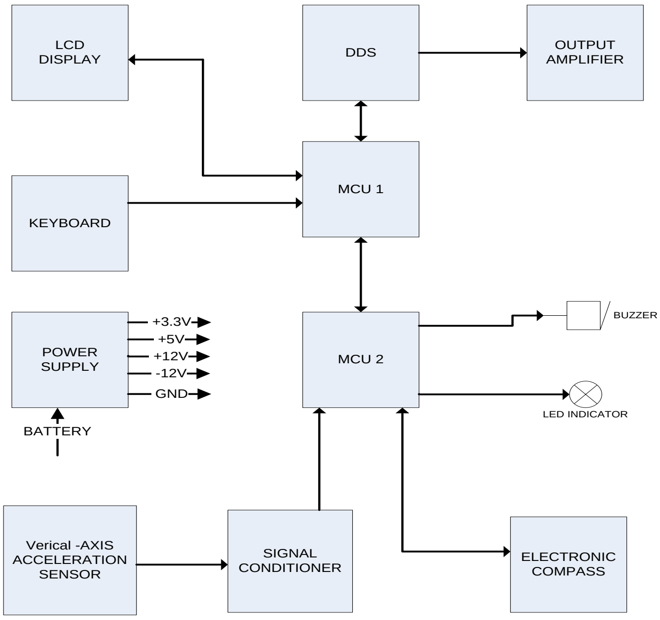


Fig.8 Electronics schematic diagram for the signal generator and the force detection circuitry

Also, not shown in the diagram of Fig.8, a wireless communication module can be included in the System. The wireless module transmits the angle of heading to a nearby computer.

Fig.9 is a picture taken from an oscilloscope. On the upper part the signal of the accelerometer in time is showing. On the right side of the signal, it can be seen signal with higher amplitude. This is when the antenna heading passes in-front of the direction of the material.

On the bottom part of **Fig. 9**, the FFT (Fast Fourier Transform) of the above signal is showing the mechanical vibration frequencies of the antenna, and the amplitude of every frequency. The scale is 2Hz (1/500ms) per division of the oscilloscope. We notice the higher peak is at the 6th division on the screen of the oscilloscope, which represents 12Hz. This is the characteristic mechanical vibration frequency of the inertia system when the force F is applied. This designates the presence of the material.

Fig.9 Picture taken from an oscilloscope [5]

2.3. Angular Positioning System

The angle of the sensor is calculated by using Gray code [7]–[11] (reflected binary code). The Gray code is a binary enumerating system that consecutive numbers differ by just one bit.

An example is shown below.

Decimal Value	Binary Code	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100

Table 1. Examples of Binary and Gray code [6]

A 9-bit Gray code is used in order to have $2^9=512$ combinations.

A cycle is 360°, so the accuracy of each step in the code is:

$$360^\circ / 512 = 0{,}703125^\circ \approx 0{,}7^\circ$$

That means that the minimum difference of the calculated angles is about 0,7°.

The disk that has the Gray code printed on it, is attached to an electronic reader communicating with a raspberry-pi computer board, that sends the readings of the angles wireless to a computer.

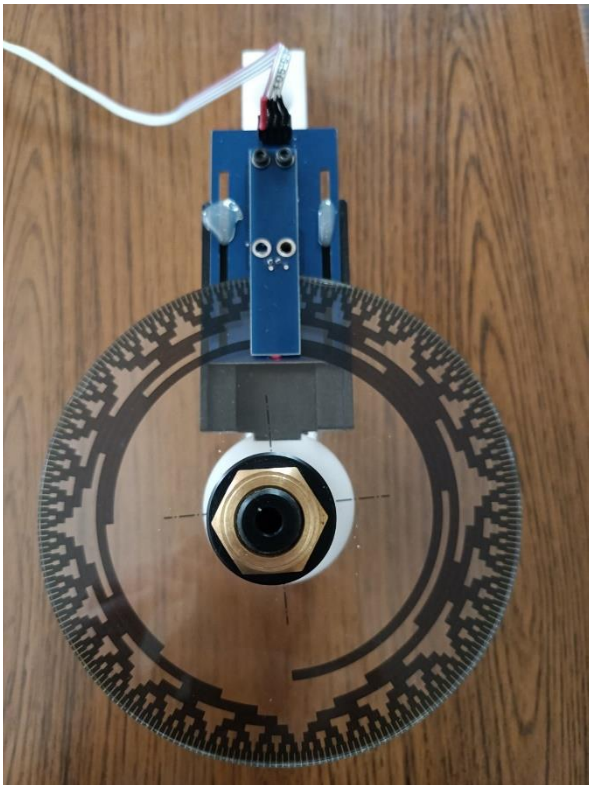


Fig.10 Vertical representation of the 9-bit Gray code

Fig.11 Electronic reader

Fig.12 Disk of Gray code attached to raspberry computer and wireless connection with laptop.

Fig.13 Complete inertia system with sensor, gray code and connection with raspberry and laptop.

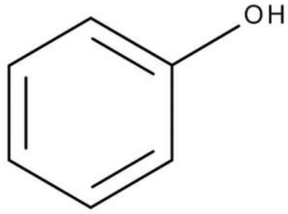
3. Experimental procedure

The experimental procedure is described below.

The electromagnetic sensor that is described in section II and a chemical substance, such as phenol, will be used for this paper.

The sensor is placed in a fixed position where it can move freely around its axis in a circular movement. The angle of the rotation of the sensor begins at 50° and stops at about 300°. Phenol is placed in a prearranged position opposite sensor. The distance between the sensor and the phenol is 5m. The quantity of the phenol in use is 1 kg and it is placed at 184.3°

Phenol, also called carbolic acid, is an aromatic organic substance with the chemical formula C_6H_5OH [12]–[16]. It is a very simple compound that responds to the frequency of 3696,8 Hz. Its formula is shown below:



The frequency of the phenol is adjusted to the sensor. The sensor is activated and starts its movement. When the antenna of the sensor is aligned with the phenol, a deceleration on the sensor can be observed. This deceleration is recorded by a raspberry-pi computer board and it is sent to a laptop. A diagram of deceleration versus angle is made (**Fig.13**).

This diagram shows the force that is applied on the antenna of the sensor, in the form of deceleration. The sensor receives decelerations that vary in intensity throughout its total movement. When the antenna of the sensor passes in front of the material in use, a force is applied on the antenna and the deceleration increases significantly.

4. Conclusion

Every substance has a certain frequency that is the corresponding frequency for each material. When the sensor emits this frequency, the material interacts with the sensor and applies a force on the antenna of the sensor.

According to **Fig.13** it is shown that when the sensor points at the direction of the phenol, while transmitting its corresponding frequency, a deceleration on the antenna is observed. More specific the deceleration is maximum among the other decelerations that are being recorded. The decelerations that appear in the angles that do not contain any substance, could be considered as noise. That means that these decelerations are just random due to mechanical factors of the movement.

It has been observed that when the sensor transmits the frequency of a substance and gets aligned with the certain substance, the recorded deceleration is always the maximum. So, if such a diagram is available then we can say by certainty that in the angle where the maximum deceleration is observed there is the material in study.

This method is already in use for identification of substances. If the frequency of a substance is known, then when the sensor emits the certain frequency it can identify every material that contains the certain substance. Also, it can find the place where the substance is as long as it is placed in a distance less than 5m.

The sensor could be used as a new method of detection of substances. A library can be created with the frequencies of substances. Then this could be a novel method for identification of substances with a short-range non-contact sensor [17]-[21]. It is a fast, relatively cheap method that does not deform the samples in study. It is easy in use and very precise. It can identify a part of a molecular structure, or the whole chemical substance, as well as the material in general.

More research needs to be done on the physics about the force applied on the antenna. Also, more work needs to be

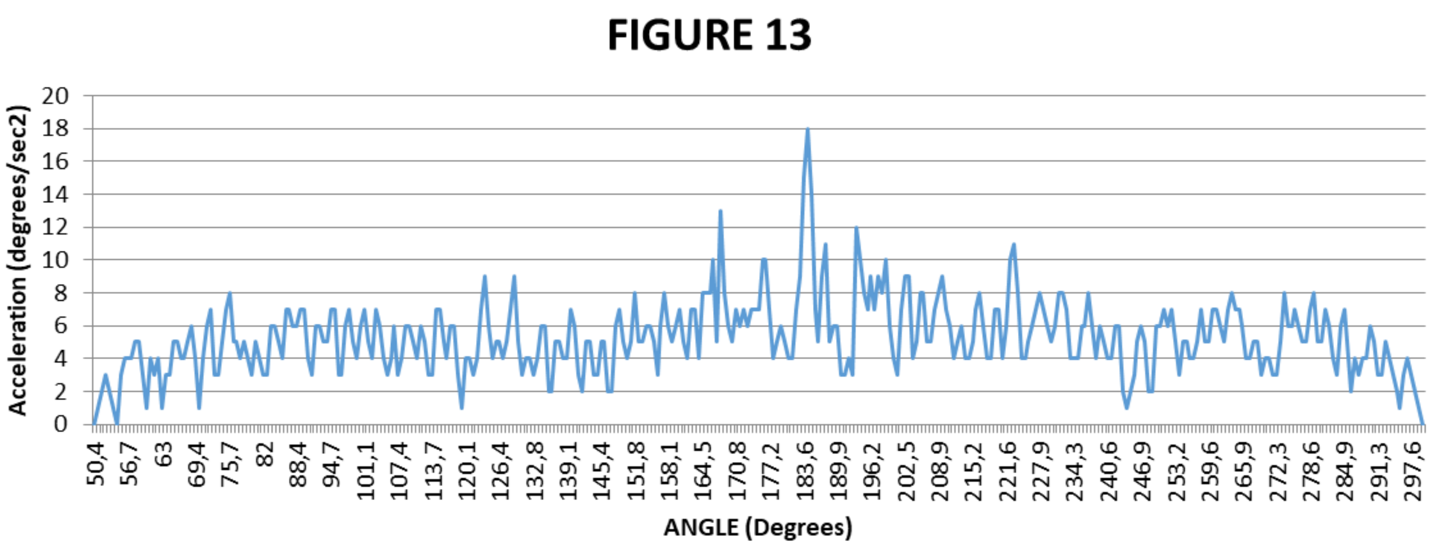


Fig.13 Graph of acceleration versus angle for Phenol

done correlating the detection frequency with the molecular structure.

Summarizing the main points of the paper:

- Every material reacts to a certain frequency, its corresponding frequency
- When the sensor emits the corresponding frequency of a material near it, a force is applied on the antenna of the sensor and a deceleration is recorded.
- This deceleration is maximum when the antenna passes in front of the material.
- It is a novel method of identification of substances and materials.
- It could be used in localization of materials.
- This method doesn't affect the substances in use. It doesn't destroy them and in most of the cases it is not necessary for the substances to be taken out of their packages in order to be studied.

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