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Development of a Modular Low Cost Robot for Scanning the Electromagnetic Field within Very Large Arbitrary Areas or Volumes

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Abstract: In this paper a new type of modular robot will be presented that is able to move a sensor with minimal inferences along predefined trajectories within a 3 dimensional space. The theory behind the mechanical method of operation will be explained in detail. Due to its versatility the field of application is quite vast. Different examples of field measurement are carried out. The setup is described in detail and the results are presented.

Keywords: Automatic positioning, Modular robot, EMC, Field measurement, Scanner.

1 Introduction

EMC often requires the knowledge of the electromagnetic field distribution within a certain plane or volume for minimization of radiation [1] or intended field generation, e.g. for an antenna. Depending on the resolution of the measurement this can be a cumbersome task carrying it out manually. Therefore robots will be used that can automatically position a sensor and realize the measurement. A lot of these robots are scanners that can move a sensor within a 2- or 3-dimensional Cartesian space. Due to its fixed spatial boundaries this type of scanner is normally always used in the same environment, e.g. inside a shielding cabin. It mostly has a metal chassis and carries the sensor at a plastic or wooden pole due to minimize the field influencing structure near the sensor. This might be sufficient for a lot of applications, but plenty of measurement environments or problems exist that prohibit totally the presence of strongly influencing materials such as metal due to falsification of the field to be measured. A good example for this is a measurement inside a GTEM cell [2].

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A further problem of most scanner systems is the fact, that they have been constructed to operate under very specific conditions regarding the measurement environment. So their use for different measurement problems is quite restricted.

Furthermore the typical Cartesian scanner using worm or belt drives to move its axes is limited to dimensions that normally do not exceed a few meters for each axis due to the rigidity of the supporting structure, the product price and the difficult availability of mechanical parts for bigger scanner constructions.

In order to overcome these problems a new type of scanner system as depicted in Fig. 1 has been developed. The position of the sensor will be accomplished by pulling and releasing strings [3] that are connected to the sensor. The scanner system features the following characteristics:

- very low cost
- extremely easy set up at different locations
- very vast scanning area
- minimum influence of the field to measure
- adaptable to very specific measurement problems

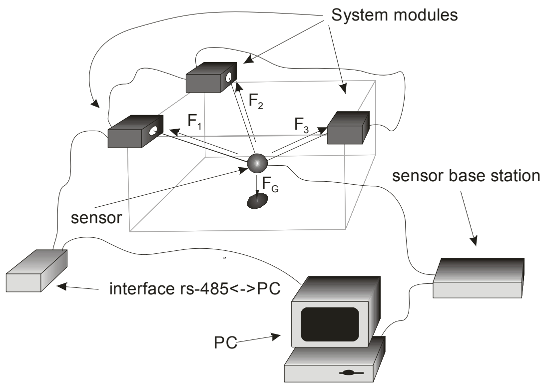

Fig. 1 – *Scanner system.*

2 Theory

The whole system is based on the possibility of positioning a point in an N-dimensional space by attaching $N+1$ strings each pulling in another direction and connected at the other end to a fixed object, e.g. a wall. The point to position lies within the space defined by the fixed ends of the strings. Giving the point in the center a certain weight, the number of strings can be reduced by one due to the gravitational force acting towards ground. Hence for a 3-dimentional space at least three strings plus the weight itself are needed.

In order to move the weight, the lengths of the strings have to be varied. The mathematical basis is graphically shown in Fig. 2. For this example a 2-dimensional problem (1) has to be solved for $i = 1, 2$. The solution of the equations is definite by applying gravity as a boundary condition.

$$r_i^2 = (x - x_{mi})^2 + (y - y_{mi})^2 \qquad (1)$$

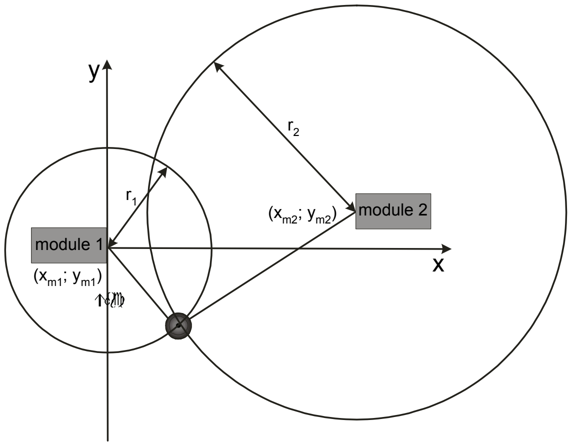

Fig. 2 – *Determination of the string lengths at a given position.*

The fixing points of the strings define the possible space to move the sensor. In order to enlarge this (theoretical) scanning area or volume, further string pulling in different directions can be applied to the weight. For this scanner system a sensor is the weight and has a typical mass of 100 g to 300 g plus the weight of the attached cabling.

The forces at the strings needed to move to a certain position within the space can be calculated using (2) and (3) as depicted in Fig. 3.

$$F_G = \sum_{i=1}^{N} F_i \sin\alpha_i \,, \qquad (2)$$

$$0 = \sum_{i=1}^{N} F_i \cos\alpha_i \;. \qquad (3)$$

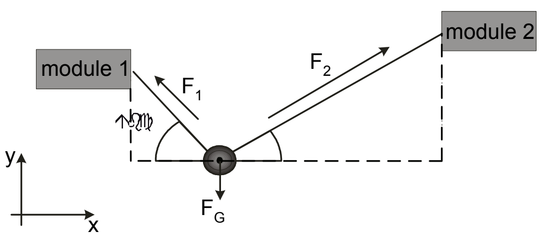

Fig. 3 – 2-D-*example to calculate the forces at the strings.*

3 Mechanics

In order to move the sensor within a space a mechanic is needed that can change the length of the strings according to geometrical calculations. This is accomplished by *N* (max. 32) modules that resemble each other totally. Each model is made out of a metal container (12×12×8 cm) that contains a motor and a rope drum. Further construction parts are the sensors to measure the string length and the tension and pulleys to guide the string as shown in Figs. 4 and 5.

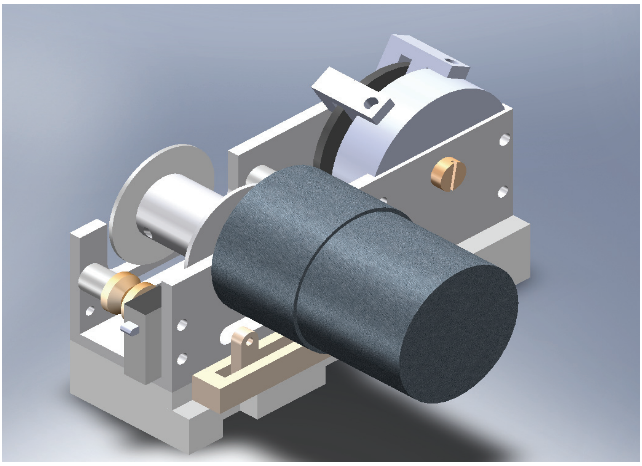

Fig. 4 – 3-D-*sketch of the mechanics inside each model.*

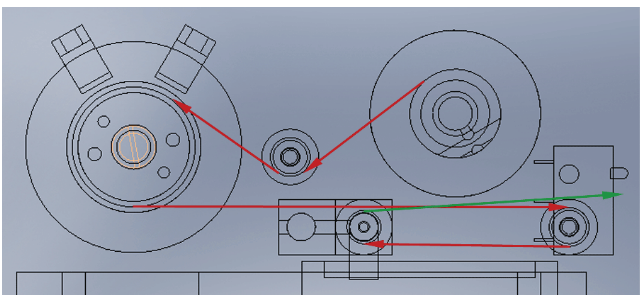

Fig. 5 – 2-D-*sketch of the mechanics showing the rope guide.*

Due to the fact that the length is measured indirectly, by counting the revolution of a pulley wheel, the string must not show any lengthening in order to place the sensor correctly. The used material for the strings is Dynema®, a material that has a very high break stress and shows very little lengthening while a pulling force is applied. For small weights such as the sensor and for an angle α according to Fig. 3 that is not too close to zero, the forces at the strings can be kept appropriately small in order to guarantee a certain positioning error due to lengthening.

The break stress of the strings is about 3% at 60 kg load. Hence the relative error of the system for a standard measurement problem is 1% and below, because the pulling force of the rope drum lies below 18 N. The absolute error due to the limited resolution of the length measuring sensor is ±1 mm.

4 Electronics and Software

The electronics inside each box consists of a µC that manages the control of the drive, the read out of the sensors and the bus communication. The used bus is a RS-485 which allows very long cabling using differential data transfer. This makes this bus ideal for use under strong field interferences. All boxes are interconnected with each other and connected to the PC via a RS-485/RS-232- or RS-485/USB-Interface. Each box has an ID, so the PC sends the commands to all, but only one module reacts.

The software written under the MATLAB® environment running on the PC handles all calculations for positioning, communication with the modules and controls acquirement of the data measured by the sensor. The sensor can either be an active standalone isotropic sensor, which is nowadays available with fiber optic communication and supply or a measurement systems consisting of a passive sensor in combination with a spectrum- or network analyzer.

5 Measurement examples

In order to show the vast fields of applications different measurements have been carried out that are of interest for EMC studies. The first one is measurement of coupling from an outer field into the metal body of a missile. Due to the slots of the missile body that are needed for the mechanical feed through for sensors and the rudders, the coupling varies by leading a sensor through the missile axially. The outer field was generated inside a GTEM cell. The missile was placed underneath the septum along the x-coordinate of the GTEM cell. Hence the impinging TEM wave creates quite a uniform outer field along the missile. The sensor inside the DUT, a very small passive dipole, was fixed and the metal body of the DUT was moved. Therefore it was possible to measure the coupling easily. The positioning of the missile was accomplished by two modules of the robot system installed at the outside of the GTEM cell. The strings were lead into the cell through a tiny hole in the wall and attached to the DUT that was put on wooden tracks in order to reduce friction and the pulling force on the strings. The measurement for different frequencies for a distance of 60 cm inside the missile is depicted in Fig. 6. The scanning resolution was 1 point/cm.

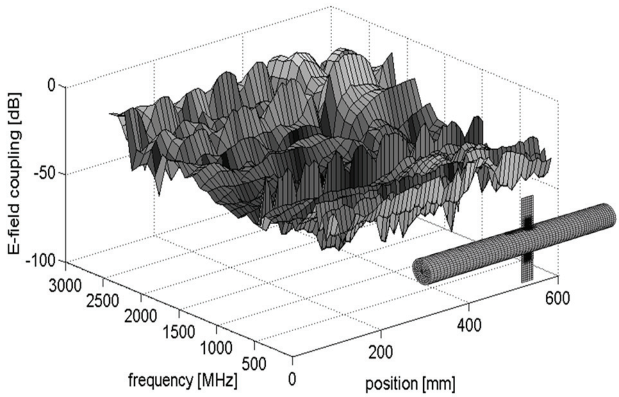

Fig. 6 – *Missile inside* GTEM *cell.*

Secondly measurements were carried out inside a shielding cabin of 2×3m. A horn antenna was placed inside the cabin the way that the radiated waves reflect at the walls. Hence a standing wave evolves. In order to measure this effect, three modules were placed at the walls of the cabin moving a small isotropic sensor at the string interconnection. The scanned area was 30×30cm at a height of 85 cm and the scanning resolution was for the *x*- and *y*-axis 1 point/cm. The spatial distribution of the field for 2.5 GHz is shown in Fig. 7. The maximum and minimum of the E-field is 98.6 V/m and 3.9 V/m respectively.

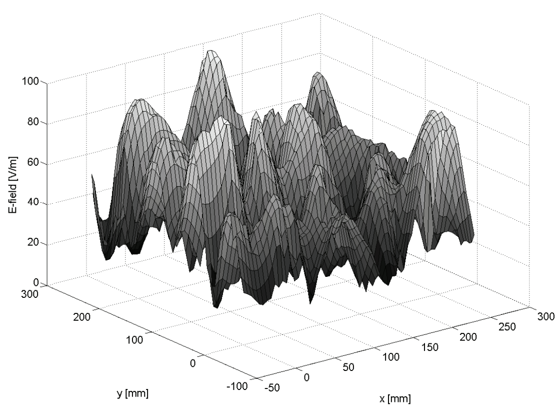

Fig. 7 – *Spatial distribution of E-field inside a shielding cabin* @ 2.5 GHz.

The same cabin was equipped afterwards with a self made mode stirrer in order to transform the shielding cabin into a reverberation chamber.

The scanner was set up at the same position using the same resolution in order to compare the result with the previous measurement. The curve depicted in Fig. 8 shows the maximum E-field over a certain hold time that was equal to the duration of one revolution of the stirrer. During this period 101 measurements were taken and the maximum was found for each spatial point.

As can be observed, the field strength is higher and the spatial blanks, where the E-field is near zero, have vanished. The maximum and minimum of the E-field is 132.6 V/m and 47.5 V/m respectively.

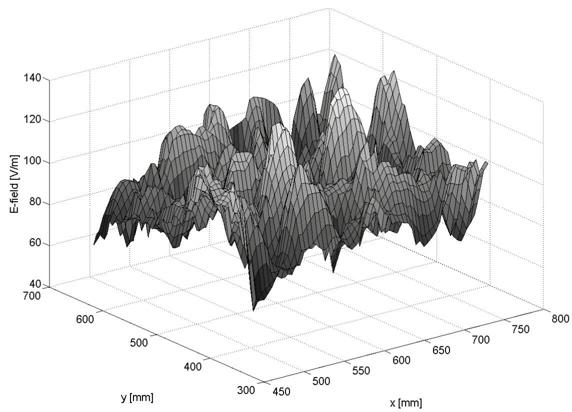

Fig. 8 – *Maximum spatial distribution of the E-field inside a reverberation chamber* @ 2.5 GHz.

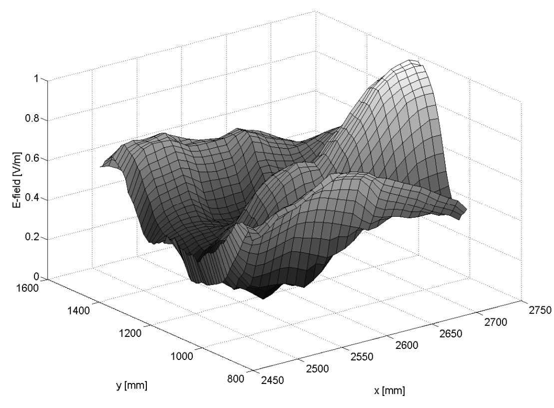

Fig. 9 – *Spatial distribution of the E-field of a radiating log-per-antenna* @ 865 MHz.

The last measurement was performed at an OATS of a log-per-antenna radiating at a frequency of 865 MHz. Although the plot observable in Fig. 9 is only over a rather small spatial range, the total measurable area was quite vast

(11 m^2). In this set up a network analyzer and a small monopole over a round surface were used as the measurement device and sensor respectively. The connection between network analyzer and sensor was accomplished with a fiber optic link system in order to keep interferences as small as possible.

6 Conclusion

A new type of robot has been presented that can scan areas or even volumes using simple mechanics. Due to the modular structure of the actuators the system is low in price, adaptable to almost every field scanning problem and easy to transport.

The movement of the sensor is accomplished by the use of strings in order to minimize the influence of the field disturbances due to the scanner itself. Furthermore, the string based suspension allows scanning small spaces as well as vast ones.

7 References

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