(U) Novel E-Field Sensor for Projectile Detection

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ABSTRACT

The development of a novel and inexpensive sensor network for detecting the electrostatic field (ESF) of a charged bullet was explored in this paper. The principle method used to measure the ESF of the passing object was based on a voltage-controlled variable capacitance. This method utilized a varactor pair and sinusoidal input signal to produce a significant change in voltage proportional to the minute change in capacitance caused by the passing object's ESF. A wired network was used to propagate the measurements to a central data acquisition unit (DAQ). The DAQ processed the data from the senor array. The results from the DAQ report the passing objects coordinated in relation to the designated central location. This paper describes the sensors, and presents results using measured (live-fire) data.

Keywords: electric field, E-field, electrostatic field, fieldmeter, bullet detection, projectile ranging

1.0 Introduction

Protection of the soldiers and the law enforcement officers from the hostile fire are one of critical priorities for the military and police. Rapid and accurate detection and localization of the hostile gunfire source allows for making informed decisions on how to counteract the danger. Several experimental and commercial sensor systems, such as BBN Boomerang [1], WeaponWatch (Radiance Tech.) [2], etc., have been developed and tested. Majority of the platforms use acoustic sensor arrays [3]. In addition, they may also utilize optical and infrared sensing methods [4] for greater accuracy and higher reliability. A comprehensive overview of existing techniques has been presented by Scanlon [5].

This work presents use of quasi-electrostatic field created by a moving, charged projectile for the projectile detection. Electric field detectors used by researchers in the published work on this topic have been of relatively simple construction. The main principle governing their operation is based on detection of the electric potential induced on a sensing, conducting element by the electric field of a passing missile. The earliest work on charged projectiles, done by Nanevicz and Wadsworth [6], describes results of experiments utilizing a shielded tube as an induction sensor. The electric potential created by bullets flying through the tube was recorded. Experiments performed by Ter Haseborg and Trinks [7] initially used similar tube sensors, but they quickly realized that this test setup is not well suited for detection of the projectiles coming from random, unspecified directions. In their later work they used three plate

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sensors, configured in a window-like structure [8] through which the bullet passed. Later work by the same authors demonstrated detection of aircrafts. They used an array of three plate induction sensors and a simple algorithm to deter mine the direction of the planes [9]. In more recent publications [10, 11, 12] researchers present increasingly more advanced algorithms and sensors. The techniques developed thus far have not received too much attention, most probably due to cost of the proposed solutions.

In order to introduce the E-field sensor to the mainstream of bullet detection solutions, it has to be robust, inexpensive, easy to use and small. In this paper the authors propose a novel sensor utilizing voltage-controlled variable capacitance. An RF amplitude-modulated varactor sensing circuit [13] is used as a front-end for the electric field detection. In a typical situation, as the bullet leaves the weapon's muzzle, it carries an electric charge ranging from 10^{-8} to 10^{-12} Coulombs [6, 7]. An electric field pulse induced by a bullet on the sensor has duration of 0.2 to 0.5 ms. This requires the sensor to operate within 2 to 5 kHz detection bandwidth. If the electric field pulse is being detected by a group of sensors in array with known distances between the sensors, so triangulation algorithms could be utilized to report the moving projectile's trajectory. In our experiments we used a wired network to feed the projectile data to the data acquisition unit.

2.0 Construction and laboratory performance of the sensor

The sensor used in the experiments utilizes an all solid state design. Construction and operation are described in earlier publications [13]. The use of a varactor couple as a modulated capacitance allows for detection of DC and AC electric fields and increases sensitivity of the sensing front-end of the circuit. The circuit is also relatively inexpensive. DC and AC performance of the sensor were tested in the Army Research Laboratory Electric-field Cage shown in Figure 1. This test setup by far exceeds recommendations given the IEEE 1308 – 1994 Recommended Practice [14], and allows for establishing uniform electric fields with better than 1% absolute accuracy [15]. The cage is 2.4 m high by 3.0 m wide (endplates) by 4.2 m long (in the field direction).

During the test the sensors are placed in the geometrical center of the cage. In our particular test, the end plates were substituted by two conducting curtains placed at 60 cm from the sensor in front and back of the sensor. This was done to enhance the electric field intensity in the space where the sensor was located.

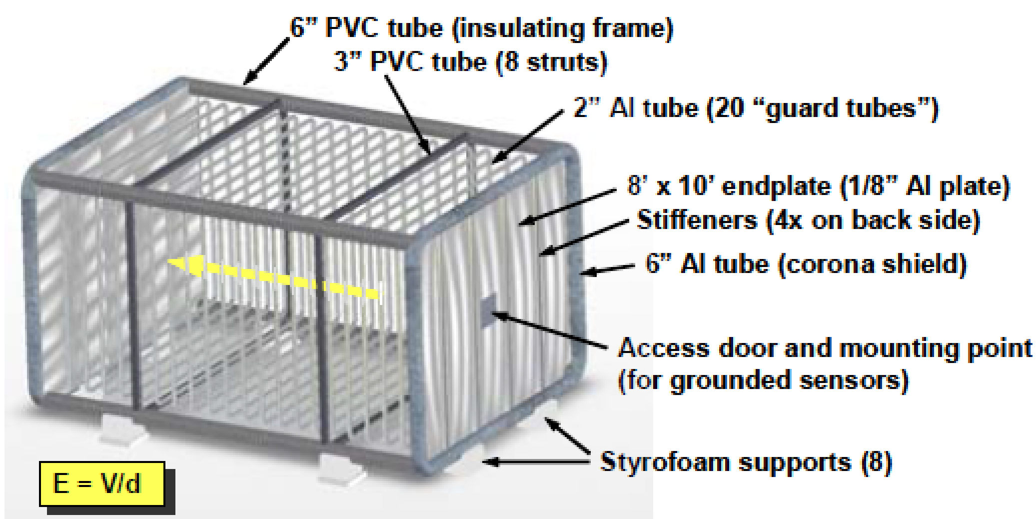


Figure 1. ARL electric field cage [15].

The sensor's frequency response to the field of 3.323 V (rms)/m is shown in Figure 2.

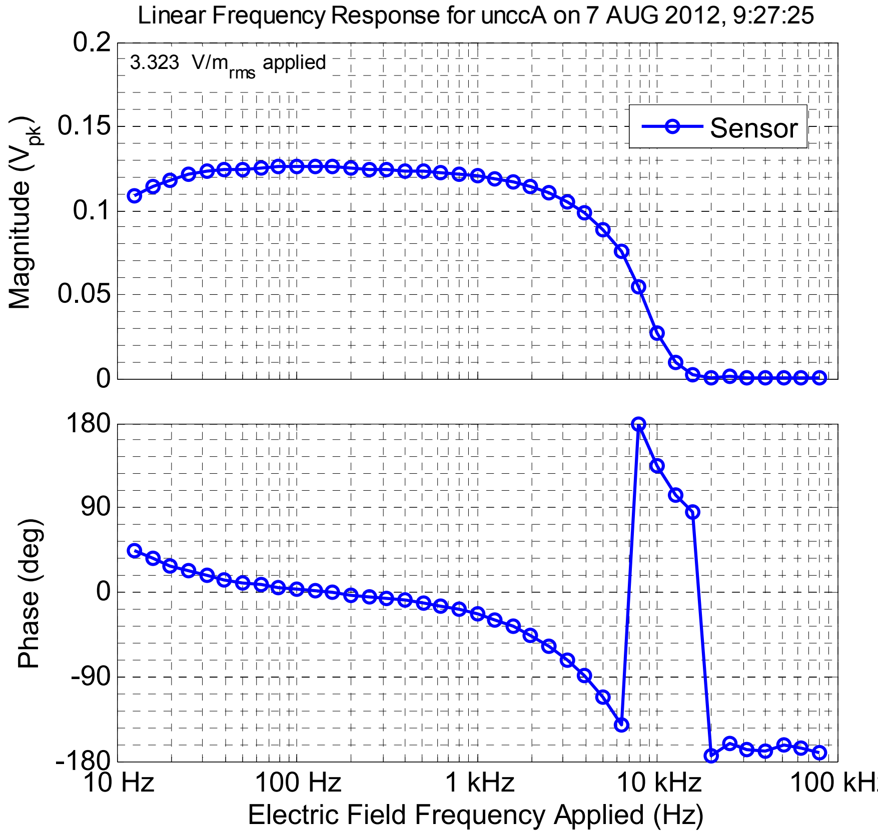


Figure 2. Frequency response of the sensor, measured in the ARL cage.

The sensor was designed to have a DC to 7 kHz bandwidth, and its present sensitivity is at 0.5 V/m. The DC performance of the sensor was tested in a different setup, shown in Figure 3. This test setup was build according to the IEEE 1308 – 1994 Recommended Practice [14]. Two aluminum plates, 1.5 m x 1.5 m separated by 0.75 m were used in the test. The plates were energized with a DC power supply (Rigol DP1308A). The sensor's Φ=75 mm disk was at the distance of 22 cm from the energized plane.

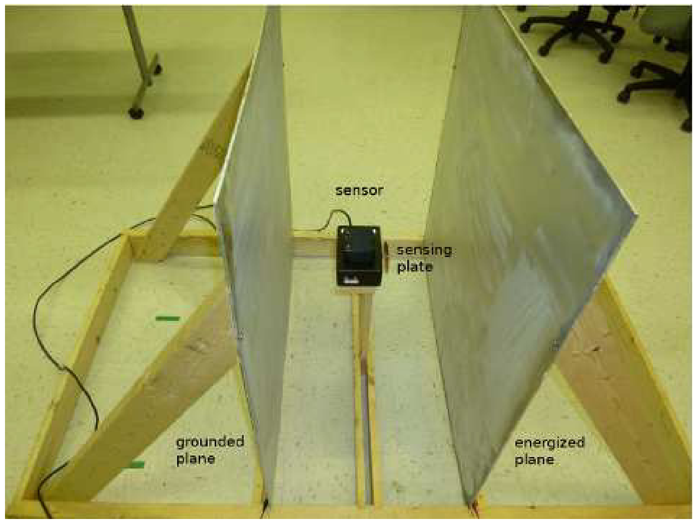


Figure 3. Test setup for the DC characteristic of the sensor.

The tests indicate that the relationship between the applied electric field and the output voltage of the sensor is linear (Figure 4).

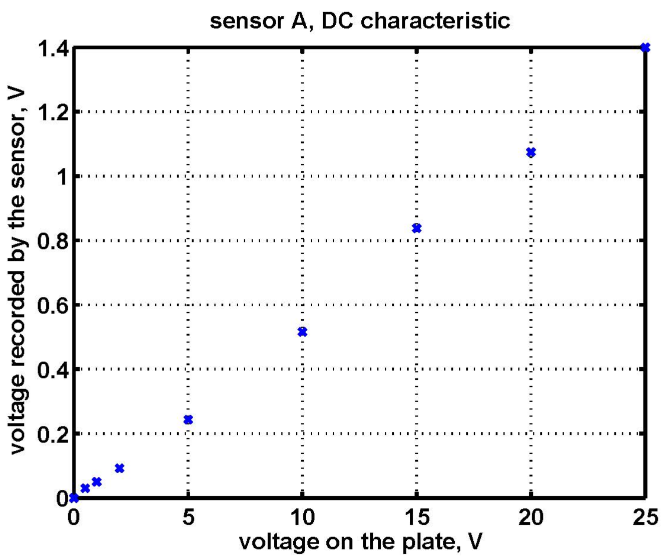
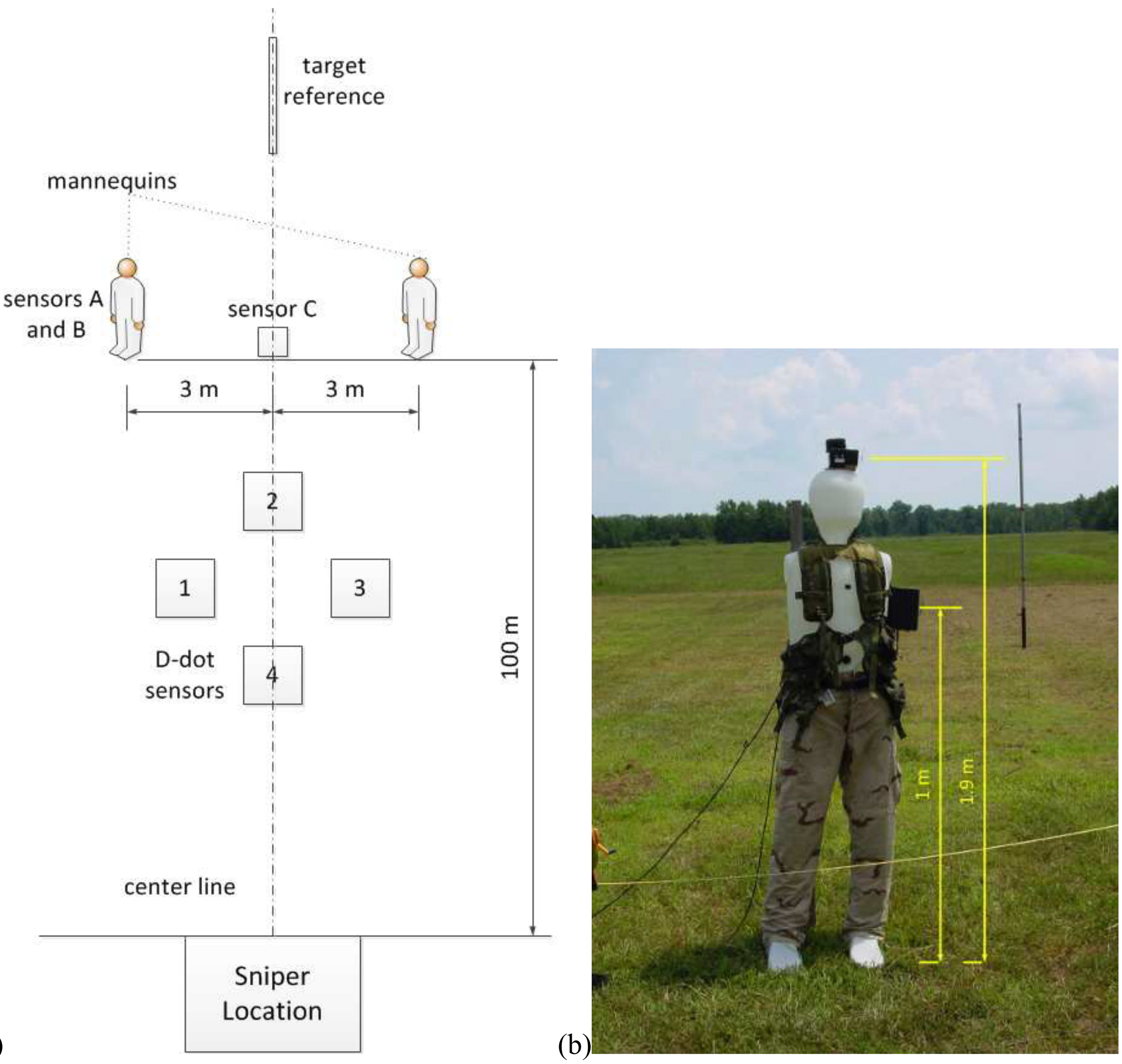


Figure 4. Example DC characteristic of the sensor.

3.0 Field tests

Three sensors were used in the field tests at the Army Research Laboratories shooting range located at the Aberdeen Proving Grounds (Figure 5(a)). After DC offset calibration the sensors were placed on the mannequin as shown in Figure 5(b).

The mannequins were located three meters on each side of the center line between the sniper location and the target reference. The target reference is a 3.5 m pole with height marks every 0.5 meter, which allow the shooter to adjust the level at which the bullets are fired.. The 0.6 x 0.6 m D-dot sensors are induction-type sensors, used for verification of the bullet's E-field detection. All shots were fired along a horizontal bullet path, without any vertical slope except for that of the ballistic trajectory. Several types of weapon were fired during the test. The test protocol called for five shots at each of the heights of 1 to 3 m in 0.5 m increments. The time of each shot was recorded to allow for correlation of the firings with the signals from the sensors. The sensors were connected via coaxial cables to the 16 channel Teac LX-120 recorder, used for collection and storage of the sensors data. The signals were simultaneously streamed over a wi-fi connection to a laptop. Figure 6 presents example detections of four rounds of caliber 50 mm fired from a M82 rifle. Note that for the “zoom area” region only sensor A and the D-dot sensor 3 indicate successful bullet detection.



(a) (b)

Figure 5. (a) Layout of the shooting range, (b) Mounting of the sensors A and B on a mannequin.

4.0 Data analysis and processing

In order to discover the bullet signature signal in the recordings from sensors B and C, a wavelet analysis was used. The bullet signature pattern detected by the D-dot and by the sensor A were used for a construction of two separate "signature" wavelets, which were then utilized in the continuous wavelet transform algorithm to detect the bullet patterns signals of the sensors B and C. Matlab wavelet toolbox was the tool of choice for the wavelet synthesis and bullet spike detection. Figure 7 shows the results of the wavelet detection performed on the signal from the sensor in the “zoom area” indicated in Figure 6.

The top portion of the graph shows the sensor signal, The bottom part shows mapping of the wavelet scaling coefficients (scale from 0 to 64, sampling interval of 10^{-12}). The marked area shows a match of the recorded signal with the shot signature.

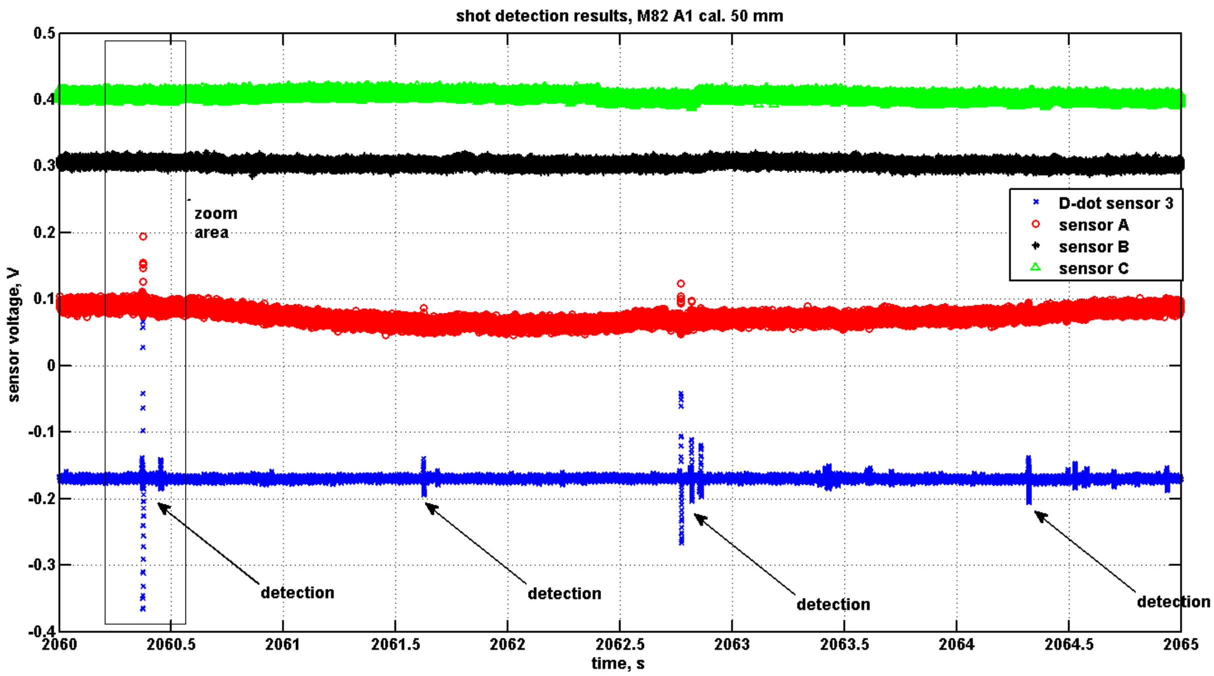


Figure 6. Raw signals detected by sensors A, B, C and the D-dot 3.

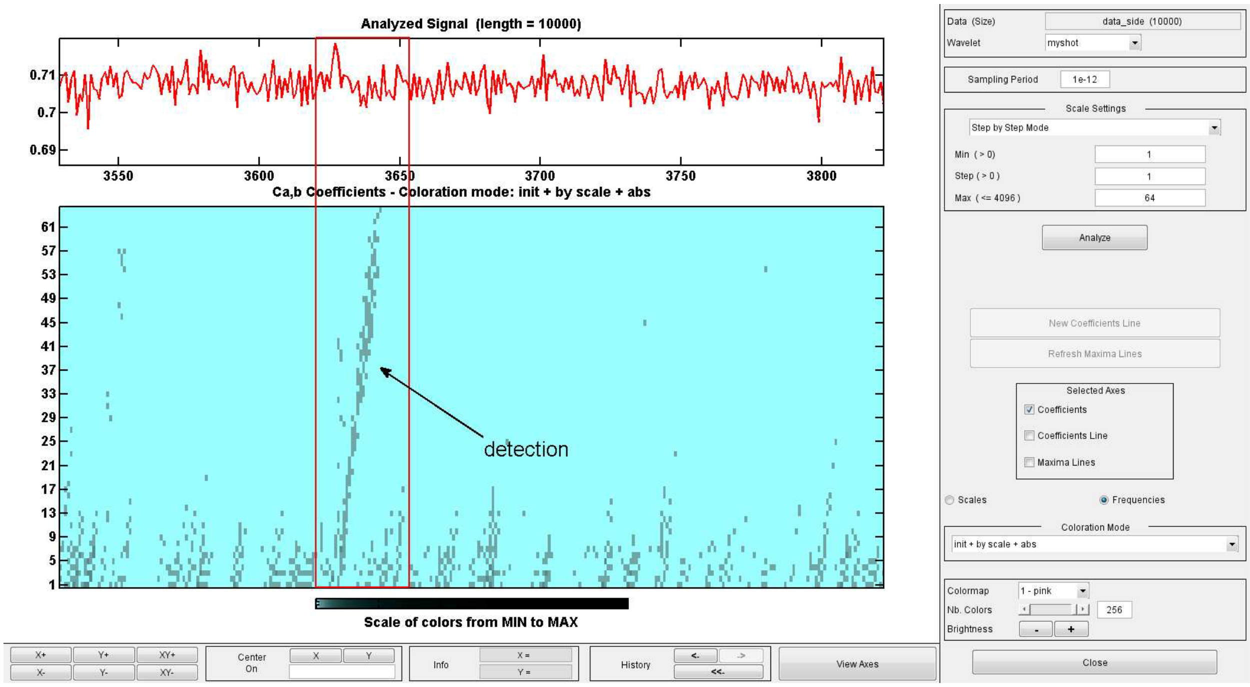


Figure 7. Shot signature detection in the signal from sensor C.

5.0 Conclusions

Use of the all solid state sensor in bullet detection requires further work and improvements to the front-end sensing circuitry. However, the wavelet-based signal post-processing can enhance detectability of the projectiles. Combination of both approaches seems to be a reasonable path for the sensor improvement. The algorithms currently used for the bullet tracking and triangulation can be enhanced with the wavelet detection algorithm. Data processing can be done either on the sensor (at a cost of higher power consumption and higher price of the sensor) or at the central location (which will introduce delays in processing and will require maintaining continuous connection between the sensor and the data center).

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