EXPERIMENTAL DEVELOPMENT OF A SMART ARTILLERY AND MINE ORDNANCE FUZE BASED ON ARDUINO MICROCONTROLLER PLATFORM

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***Abstract**: Today’s battlefield is ever-changing in terms of weaponry demands and engagement criteria. Older artillery ordnance is often struggling to meet the modern battlefield demands and does not provide the operator with a wide range of capabilities. This combination of constraints coupled with the performance of conventional artillery munitions has often limited the commander’s options and decreased the effectiveness of artillery. Meeting the modern battlefield demands requires the performance and capabilities of existing ordnance to be increased. This paper researches the creation of a smart fuze that will provide increased flexibility and capabilities at a price that permits its use in tactically significant quantities as well as for training.*

Keywords: ARTILLERY FUZE, SMART FUZE, INCREASED CAPABILITIES.

1. Introduction.

Although maneuver warfare is valid under certain circumstances, the nature of war and the realities of the modern battlefield call for more flexible weaponry [1]. Current ordnance faces an increased demand in percussion and efficiency in order to fulfill its battlefield role efficiently. The smart fuze researched in this paper aims to transform existing artillery projectiles into affordable “SMART” weapons.

The smart fuze project enhances and increases current capabilities of artillery projectiles. The smart fuze further mentioned in this report only as “SF” is a fuze sized module used in lieu of a standard fuze on existing artillery projectiles. The fuze installs in the projectile fuze well on already existing ordnance – in the field as needed.

The SF is a modular, multipurpose device designed to incorporate multiple fuze functions in one package. The device consists of a fuze-like kit that contains a microcontroller, power supply, customizable range of sensors, electronic circuitry and different fuze function modes. The SF is a combination fuze that incorporates wide range of capabilities and functions. The SF incorporates the following fuze capabilities and functions: Munition time fuze (MTF), Proximity or variable fuze (VTF), Percussion or impact fuze function [2]. The SF has the capability to operate both as a no delay type fuze that functions immediately on contact with any thin material (for example, the thin sheet metal skin of an aircraft) or with a delay to keep the burster from going off until after penetration [2]. The fuze is capable to go off either on impact or after the time set, whichever occurs first.

The SF functions in conjunction with command and control software that provides additional range of capabilities. The software is open source and provides the user with ease of use and high level of customizability. The operator has the freedom to choose the needed function from what the objective dictates given the circumstances and battlefield conditions. That provides the SF with the much needed edge over other mechanical fuze platforms and utilizes the full potential of the system. The SF strives to provide the necessary precision and flexibility at a price that permits its use in tactically significant quantities as well as for training. The SF utilizes electronic components that replace their mechanical counterparts found in the majority of the traditional fuzes.

Based on the shown above in this report, research is made in the creation of this low-cost, highly reliable, fuze-sized device that provides additional as well as improved traditional fuze functions on the modern battlefield.

2. Assembling, testing and configuring different fuze sensors and components.

2.1. Objective: Setting up, configuring and installing different sensor components.

2.2. Tasks:

- Configuring the microcontroller;

- Setting up, configuring and testing the ultrasonic proximity sensor;

- Setting up, configuring and testing the Passive Infrared (PIR) sensor;

- Setting up, testing and configuring the gyro-sensor and accelerometer.

- Configuring the microcontroller.

In order for the goal of this report to be achieved all the hardware components inside the fuze need to be carefully assembled, programmed and configured to function harmoniously with the software and the operator. The main component of the fuze that executes the software and controls the other hardware components is the microcontroller. The microcontroller in the fuse is based on the Arduino platform. The choice of the Arduino platform is driven by the fact that Arduino is an open-source electronics platform based on easy-to-use hardware and software [3]. Arduino boards are able to read inputs - light on a sensor, execute software instructions, or another electronic device - and turn it into an output - activating a motor, turning on an LED [3], executing a command etcetera. The board is instructed what to do by the use of the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing [3]. The main assembly model of the SF utilizes the Arduino Uno platform. Arduino Uno is a microcontroller board based on the ATmega328P microchip[4]. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button [4].

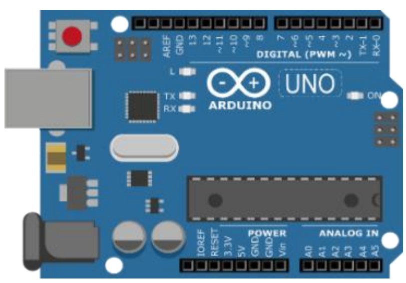

***Fig. 1:** Arduino Uno board overview.*

Arduino Uno is fitted with the ATmega328 single-chip microcontroller. The functionality and configuration of all the components is tested with the microcontroller before they are assembled and fitted in the fuze model. The Arduino Uno board used in the project can be replaced with a much smaller board with the same functions and capabilities as the Arduino Nano board, making a much smaller fuze model.

- Setting up, configuring and testing the HC-SR04 ultrasonic proximity sensor;

The ultrasonic range finder is a module that measures distance. The module is able to determine the distance to an object, or to detect when something is near the sensor, like a motion detector. The module is ideally suited for projects involving navigation and object avoidance. The module is capable of operating in day and night conditions. The ultrasonic range finder used in the SF is the HC-SR04, which can measure distances from 2 cm up to 400 cm with an accuracy of ±3 mm [5].

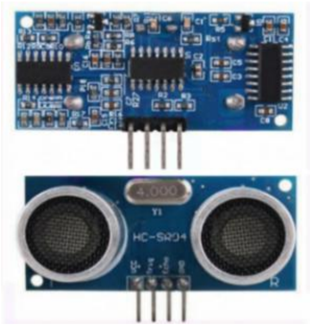

Fig. 2: *HC-SR04 Ultrasonic Sensor.*

The transmitter emits 8 bursts of a directional 40KHz ultrasonic wave when triggered and starts a timer [6]. Ultrasonic pulses travel outward until they encounter an object, which causes the wave to be reflected back towards the unit. The ultrasonic receiver would detect the reflected wave and stop the stop timer. The velocity of the ultrasonic burst is 340 m/s in air [6]. Ultrasonic range finders measure distance by emitting these ultrasonic sound pulses that travel through the air until they hit an object. When that pulse of sound hits an object, it's reflected off the surface and travels back to the ultrasonic range finder. The ultrasonic range finder then measures how long it takes the sound pulse to travel in its round trip journey from the sensor and back. It then sends a signal to the Arduino with information about how long it took for the sonic pulse to travel. Knowing the time, it takes the ultrasonic pulse to travel back and forth to the object, and also knowing the speed of sound, the Arduino can calculate the distance to the object. The formula relating the speed of sound, distance, and time traveled is:

(1) $S = \frac{d}{t}$

Where S – speed, d – distance, t – time.

Rearranging this formula, we get the formula used to calculate distance:

(2) $D = s \, . \, t$

The time variable is the time it takes for the ultrasonic pulse to leave the sensor, bounce off the object, and return to the sensor. This time is divided in half since we only need to measure the distance to the object, not the distance to the object and back to the sensor. The speed variable is the speed at which sound travels through air. In order for the sensor to achieve best results and maximum range, the object that the sensors detect should be larger than 0.5 cubic meters, the nearer the target object, the smaller it may be [7]. On the front of the ultrasonic range finder are two metal cylinders. These are transducers. Transducers convert mechanical forces into electrical signals. In the ultrasonic range finder, there is a transmitting transducer and receiving transducer. The transmitting transducer converts an electrical signal into the ultrasonic pulse, and the receiving transducer converts the reflected ultrasonic pulse back into an electrical signal. The HC-SR04 ultrasonic range finder has four pins: Vcc, Trig, Echo, and GND. The Vcc pin supplies the power to generate the ultrasonic pulses. The GND pin is connected to ground. The Trig pin is where the Arduino sends the signal to start the ultrasonic pulse. The Echo pin is where the ultrasonic range finder sends the information about the duration of the trip taken by the ultrasonic pulse to the Arduino. To initiate a distance measurement, a 5V high signal is send to the Trig pin for at least 10 μs. When the pulse hits the receiving transducer, the Echo pin outputs a high voltage signal.

For the purpose of this paper a rangefinder module is assembled that outputs the distance measurements to the microcontroller. The microcontroller then utilizes the obtained data and activates the fuze at a distance set in the software by the operator. This distance set in the software is the proximity distance at which the operator wants the fuze to execute the explosive function of the projectile. The microcontroller is connected to the fuse's detonator thus when voltage is applied to the detonator from the microcontroller the projectile's detonation is initiated. The detonator in the prototype is simulated via the red LED and the detonation is indicated by the buzzer. Using Autodesk circuits, a working model is simulated before the creation of the prototype model (Fig.3).

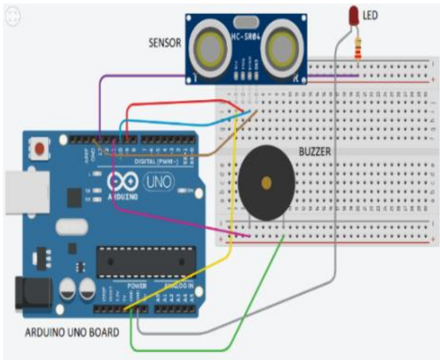

Fig. 3: *Project simulation using Autodesk circuits.*

After simulating the project and testing the working capabilities of the hardware the software is uploaded to the microcontroller. The assembled prototype board is shown in (Fig.4).

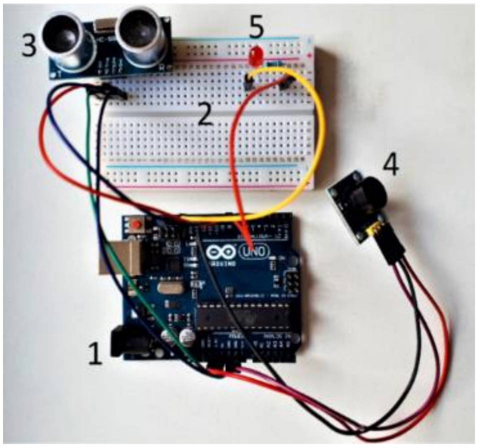

Fig.4: *Project assembly.*

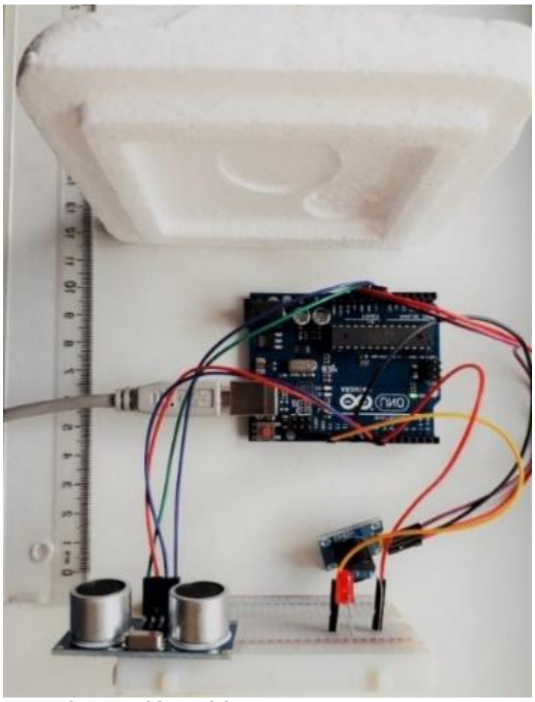

Fig. 5: *Testing the assembly model.*

In ***Fig.5*** the Arduino successfully detects the presence of the object in front of the sensor and turns on the LED when the object is at the desired distance set in the software. The components used in the assembly project are listed in (Table.3):

Table. 1: *Components list.*

Number	Component
1	Arduino Uno
2	Breadboard
3	HC-SR04
4	Buzzer
5	LED and Resistor

Using SOLIDWORKS software a 3D model housing the sensor is created. The HC-SR04 sensor will be fitted inside the model after which the model will be assembled on the fuze.

- Setting up, configuring and testing the Passive Infrared (PIR) v1.0 and v.1.1 sensors;

The PIR sensor provides the fuze with the capability to detect personnel and therefore initiate the explosive function of the projectile. The PIR, "Passive Infrared", "Pyroelectric", or "IR motion" sensor is capable of detecting personnel moving in and out of the sensor's range. The PIR sensor is made of a pyroelectric sensor [10], which can detect levels of infrared radiation. Along with the pyroelectric sensor, the chip is also equipped with supporting circuitry, resistors and capacitors [8]. The chip uses the output of the sensor and after processing emits a digital output pulse from the analog sensor.

The PIR sensor itself is equipped with two slots in it. Each slot is made of a material that is sensitive to IR. There is some distance between the lens and the sensor itself. [8]. When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiated from the room, or walls or outdoors. When a heat signature, for example, a human or an animal passes by, it first intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change.

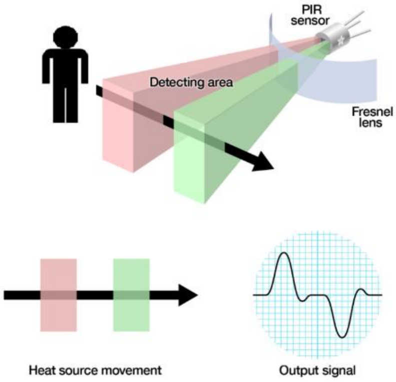

Fig. 5: *PIR sensor working principle.*

The IR sensor itself is housed in a hermetically sealed metal can to improve noise/temperature/humidity immunity. There is a window made of IR-transmissive material [9] that protects the sensing element. Behind the window are the two balanced sensors.

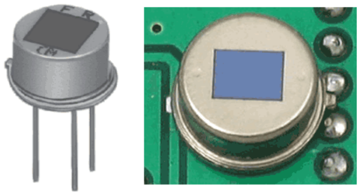

Fig.7: *Pyroelectric Infrared Sensor [9].*

The lens of the PIR is the component that determines the change in the breadth, range and the sensing pattern. The sensor uses a simple lens. They condense a large area into a small one, for this reason the sensor is actually equipped with Fresnel lenses. The Fresnel lens condenses light, providing a larger range of IR to the sensor (Fig10).

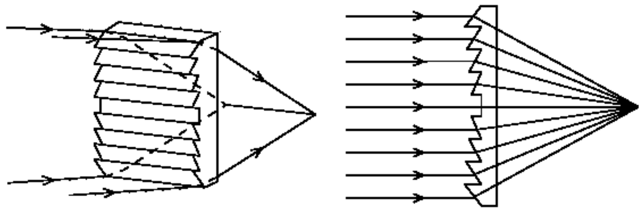

Fig.8: *PIR sensor's Fresnel lens dome.*

The PIR sensor is added to the fuze like model. The PIR sensor in the model will feed data to the microcontroller which in turn will initiate the explosive function of the projectile when the sensor detects a heat signature. The experimental circuit schematics made are presented in (Fig. 10). The output pin of the sensor is connected to pin-8 on the Arduino Board and when an object is detected the pin-7 will activate a voltage relay connected to the fuze detonator.

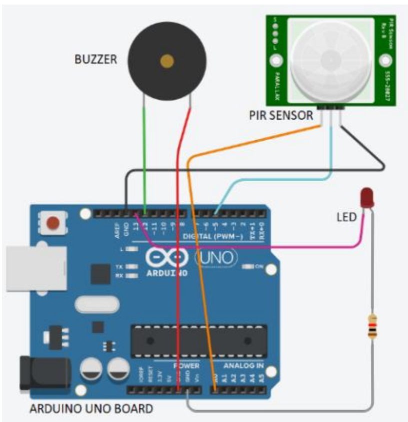

Fig.9: *Project simulation using Autodesk circuits.*

After simulating the project and testing the working capabilities of the hardware, the software is uploaded to the microcontroller. The assembled prototype board is presented in (Fig.10).

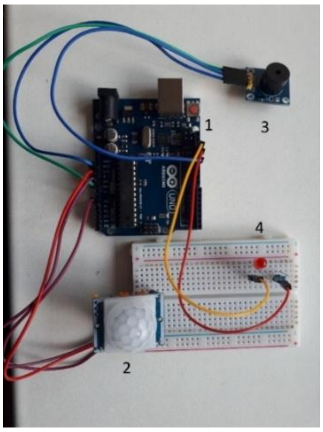

Fig. 10: *PIR sensor project assembly.*

The components used in the assembly are listed in (Table.4):

Table. 2: *Components list.*

Number	Component
1	Arduino Uno
2	PIR sensor
3	Buzzer
4	LED and Resistor

Using SOLIDWORKS software a 3D model is created. The PIR sensor will be fitted inside the model after which the model will be assembled on the fuze. After everything is assembled and connected the command code is written and uploaded to the Arduino board. Different PIR sensor (Fig.11) is also used working on the same principles.

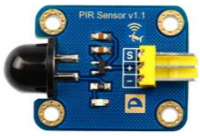

Figure 11: *PIR Sensor v1.1.*

A prototype model is assembled and presented in (Fig.12). The microcontroller used is the Arduino Uno board.

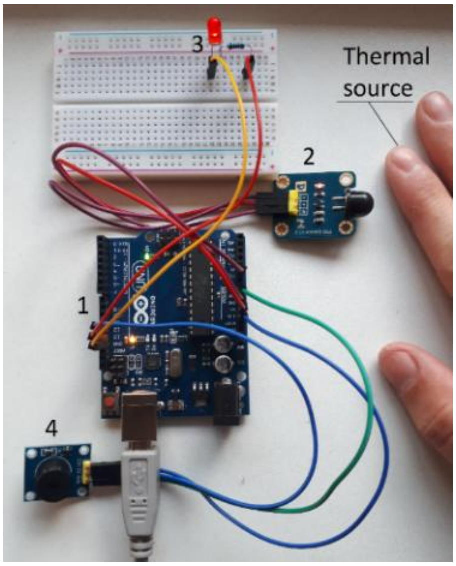

Fig 12: *PIR v1.1 project assembly.*

The components used in this assembly are listed in (Table 3).

Table. 3: *Components used in the assembly.*

Number	Component
1	Arduino Uno
2	PIR sensor v 1.1
3	LED and Resistor
4	Buzzer

The PIR sensor in the model is able to detect the thermal presence of the human hand and initiate the LED. Using SolidWorks 3D model are created for both PIR sensor. The models are fitted on top of the fuze body.

-Setting up, testing and configuring the ADXL345 gyro-sensor and accelerometer.

The MEMS are very small systems or devices, composed of micro components with a very small size. These components are made of silicon, polymers, metals and/or ceramics, and they are usually combined with a CPU (Microcontroller) for completing the system [10]. The working principle of the Micro-Electro-Mechanical-Systems (MEMS) sensors will be briefly explained below.

MEMS measure acceleration by measuring the change in capacitance. Its micro structure is displayed in (Fig.13). The MEMS chip has a mass attached to a spring which is confined to move along one direction and fixed outer plates. So when an acceleration in the particular direction is applied the mass moves and the capacitance between the plates and the masses changes. This change in capacitance will be measured, processed and will correspond to a particular acceleration value.

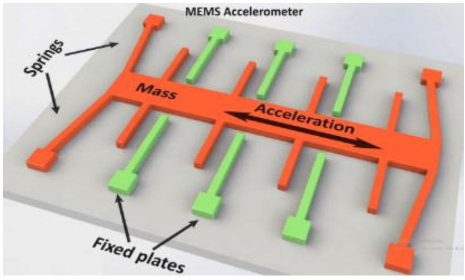

Figure 13: *MEMS chip working structure and principle of action.*

The accelerometer used in the project is the ADXL345 chip (Fig14).

Figure 14: *ADXL345 overview.*

The ADXL345 is a small, thin, low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 g. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2 C digital interface [11].The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (4 mg/LSB) enables measurement of inclination changes less than 1.0° [11]. Several special sensing functions are provided. Activity and inactivity sensing detect the presence or lack of motion and if the acceleration on any axis exceeds a user-set level. Tap sensing detects single and double taps. Free-fall sensing detects if the device is falling. [11].

Considering the applications listed above the ADXL345 is the perfect choice for the SF. The ADXL345 will function as the fuze safety feature as it will act as a safety-detonation mechanism. The safety-detonation mechanism will detect whether or not the fuze has been fired from the artillery cannon, ensuring that the fuze only works when intended to do so. This process is achieved in conjunction with the hardware and software. Given the sensing capabilities of the accelerometer in particular: free-fall sensing and activity, inactivity sensing. The ADXL345 can detect acceleration and measure it in G-force. Setting up the software to arm the fuze only after an acceleration greater than 3G is detected by the accelerometer ensures that the ordnance will not detonate during transportation or when handled or dropped. The acceleration safety setting is set for 3G. Such a high level of acceleration is sufficient to ensure safety given ordnance is handled accordingly to the safety measures or dropped unintentionally. Because the ADXL345 sensor is the main safety feature of the fuse, the device must function properly at all times in order for safety to be guaranteed. The ADXL345 is the module connected with the fuze safety feature. In order for safety to be guaranteed it is critical that this device functions properly at all times. Thus the ADXL 345 is equipped with a self-test capability. The self-test change is defined as the difference between the acceleration output of an axis with self-test enabled and the acceleration output of the same axis with self-test disabled [11]. This definition assumes that the sensor does not move between these two measurements, because if the sensor moves, a non–self-test related shift corrupts the test [11].

Using Autodesk circuits, the ADXL345 module is simulated with conjunction with the Arduino board (Fig 15).

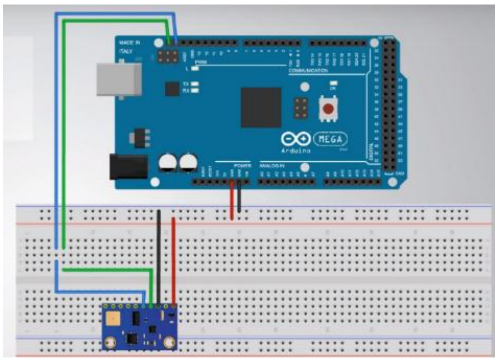

Figure 15: *Autodesk circuits smulation.*

Testing the working capabilities of the sensor is shown in (Fig.16).

Figure 16: *Testing the module.*

The pen on fig 18 shows the x axis of the sensor so if the sensor is rotated around the axis we can detect the changes on the serial monitor. Unfortunately, the gyro results are not stable due to the fact that they drift as the time goes so in order to get more accurate angles data the gyro needs to be combined with the accelerometer data,

3. Conclusion.

The components configured in this paper have the capabilities to function as a fuze with multiple fuzing capabilities. With the following fuze functions: personnel detection, proximity detection and time fuzing. The SF model is provided with a safety mechanism, allowing for safe ordnance handling and transportation.

The microcontroller used in the project was successful in executing the software commands. The microcontroller was able to control the different sensor components to gather and analyze data from them working in conjunction with the software. The Arduino Uno is a suitable component for the SF as it meets the needed requirements.

The ultrasonic proximity sensor researched in this paper provides distance measuring and proximity sensing capabilities at a very limited range. The HC-SR04 Ultrasonic sensor range proves to be unsuitable for the needs of the smart fuze project as it has a range of 400cm that proves to be insufficient for the fuze purposes. The sensor accuracy is also inadequate as it proves to degrade rapidly at larger distances. Considering the limited range and accuracy the sensors is it unsuited for use in the SF. A specialized sensor designed purely for military purposes, which has a higher range and accuracy, must be designed in order to be used in an optimal fashion and meet the modern day battle criteria.

The PIR sensor researched in this paper was successfully able to detect heat signatures entering and exiting the sensor's effective range. The PIR sensor effective range and accuracy proved insufficient for the purpose of the smart fuse as they were very limited which in turn demands for a specialized sensor to be researched purely for military purposes.

The accelerometer chip used in the project was able to measure accelerating. The chip meets the necessary requirements for the smart fuze, thus it is a valuable choice for a fuze like kit like the SF. Furthermore, with the build in self-test the device adds additional safety to the SF as it is ensured to function properly.

In perspective the stress applied to the fuze body when fired must be investigated further. More research needs to be conducted with the use of more sophisticated electronic components for the proximity and distance sensors that have a higher degree of accuracy and precision, as the ones currently used prove to be insufficient to provide the fuze with the required range and functionality.

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