Evaluating the Effectiveness of Low Cost Sensors for Non Invasive Detection of Shallow Buried Archaeological Artifacts

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Abstract

Non invasive technology is becoming more relevant for the field of archaeology because it allows for the location of hidden artifacts without the destruction of the environment. But specialized instruments like Ground Penetrating Radar or high quality magnetometers are out of the price range for most researchers. This paper investigates the usefulness of low cost ultrasonic, infrared, and magnetometer sensors for the location of shallowly buried artifacts in sand, clay, and mixed gravel soils. Testing with ceramic, metal, bone, and stone artifacts indicates that the ultrasonic sensor is effective in sand, the infrared sensor has very shallow range limitations, and the magnetometer has the highest location accuracy for metal objects.

Keywords: Archaeological surveying, ground penetrating radar, ultrasonic detection, infrared reflectance, magnetometry, non invasive archaeology

1. Introduction: The effectiveness of low cost sensors in archeology

Archeological sites hold fragile and irreplaceable artifacts worth thousands of years of history buried beneath the ground and it is crucial that these artifacts must be preserved effect. Traditional excavation methods risk damaging these precious art facts and manually, digging his time intensive and often not destructive henceforth non invasive methods are used in archaeological fields to avoid extensive harm onto the fragile land while professional tools like Ground Penetrating Radar (GPR) electrical resistivity tomography, LiDar, and high end fluxgate magnetometers are widely used with the average cost of 14,000 to 80,000 respectively. LiDar is a key part in various phases of archaeology but can cost up to 500,000 for high end precise results which limits accessibility for schools, small excavation teams, and low resource communities, but as the years passed by affordable drone, carrying ladder has stepped onto the archaeological scene.

There are a few low cost ground penetrating sensors in the market right now major ones being: ultrasonic, infrared, and magnetic field variations. Ground Penetrating Radar (GPR) uses electromagnetic waves and is the standard for ground penetrating tasks like locating buried utilities, geological surveys, mine detection, etc. while GPR is wildly used Non Destructive Testing (NDT) method, professional systems that guarantee precision are expensive.

The effectiveness of these low cost sensors for ground presentation is highly dependent on the target material and the surrounding medium's property like moisture content and material type. For example, ultrasonic testing works well for detecting air gaps in concrete, but not small inclusions below them while GPR struggles with air voids but detects concentrated inclusions effectively

Meanwhile the rise of low cost sensor, driven by robotics, smart devices and hobby electronics this presents a new possibility:

Can simple, inexpensive sensors detect buried objects the same way professional tools do, at least at shallow depths?

2. Literature Review

Archaeology relies heavily on methods that minimise disruption to the site. Manual probing, stratigraphy, and small trenches remain common approaches (Carver, 2018; Harris, 2019; Renfrew & Bahn, 2020), though each has limitations.

Ground Penetrating Radar (GPR)

GPR is one of the most effective non invasive tools because it can detect objects several meters underground (Goodman, 2018). However, its accuracy depends on soil conductivity and moisture content, and the equipment is expensive.

Ultrasonic Sensing

Ultrasonic sensors work by sending sound waves through soil and measuring the reflections. They are good at detecting gaps or density changes but do not perform well in moist or clay heavy soils due to signal loss (Zhu et al., 2017).

Infrared Surface Reflectance

IR methods are mostly useful for detecting disturbances close to the surface. Parcak (2019) showed that IR imaging can reveal subtle temperature or reflectance differences but becomes unreliable for deeper artifacts.

Low Cost Magnetometry

Basic magnetometers can detect metal objects by measuring minor changes in the magnetic field. Smartphone magnetometers have even been tested with some success for shallow metal detection (Magnusson, 2016; Bogomolov, 2019).

Robotics and Archaeology

Robotic systems are slowly becoming part of archaeological research (Khosravani, 2020), but using low cost sensors on small educational robots is still relatively unexplored.

3. Methodology

Experiment 3.1: Construction of the Controlled Archaeological Soil Bed

A controlled testing environment was created to simulate three most common archaeological soil types. A transparent plastic container measuring (30 × 20 × 15 cm) was used for testing. The space was divided into three equal compartments using aluminum dividers, each representing a soil composition, sand, clayey and mixed gravel, respectively. Each compartment was filled with a different soil type to create controlled testing conditions. The first compartment consisted of fine sand, arranged into a uniform 10 cm layer to represent a highly porous and consistent sediment. The second compartment held a 10 cm layer of moist, clayey rich soil, selected to mimic low porosity archaeological sediments where signal penetration is typically reduced. The third compartment used a mixed gravel made from coarse garden soil combined with gravel fragments, with fragments of rocks to replicate the uneven layer similar to conditions found in naturally rocky archaeological sites.

Each soil type was leveled to maintain uniform density. The container design ensured consistent boundary conditions while allowing repeated, controlled trials for all sensors

Artifacts used:

Artifact Types	Material	Size	Archeological relevance
A	ceramic pieces	5 cm	Pottery remains
B	coin	2.3 cm	Trade objects
C	dog bone	13.8 cm	Previous living remains
D	stone	7 cm	Historic tools

3.2 Artifact Burial

To evaluate detection accuracy, a test artifact was buried at three controlled depth ranges. Shallow tests were done at 2 to 3 cm, medium depth tests at 5 to 6 cm, and deep tests at 8 to 10 cm. These levels allowed the sensors to be compared fairly across different burial depths.

Small trenches were created in each soil compartment, and the artifact was placed at the selected depth. The soil was leveled to avoid leaving visible surface cues. Each depth test was repeated three types per soil type to reduce random error.

3.3 Archaeological Comparison Techniques

To provide a baseline for evaluating the performance of the proposed robotic system and low cost sensors, several standard archaeological comparison techniques were conducted. Manual probing with thin steel rods was used to find subsurface anomalies by detecting changes in resistance. Visual soil stratigraphy was assessed by examining colour, texture, and layering differences within the excavated soil profile to find potential artifact bearing areas. Then, student excavation time measurements were recorded during controlled digs to set up a human performance baseline, allowing comparison of excavation speed, precision, and safety between manual techniques and the micro excavation robotic prototype.

3.4 Data Collection Procedure

Data acquisition followed a standardized protocol to ensure consistency across all soil types and burial depths. For each trial, a test artifact was buried at a predetermined depth within the selected soil compartment. After burial, the sensor array was positioned above the surface and aligned to a 5 cm × 5 cm scanning grid, which defined the measurement points across the soil bed.

At every grid position, the sensor was held at a fixed height, and 50 consecutive readings were recorded. From these readings, both the mean signal intensity and the signal variability were calculated. A detection was classified as 'YES' if the mean signal exceeded the baseline noise threshold for that soil type, otherwise the result was marked as 'NO.'

This procedure was repeated systematically for all three soil layers and for all burial depths tested. Multiple replicates were conducted to minimize random error and increase reliability of the dataset.

3.5 Sensors used

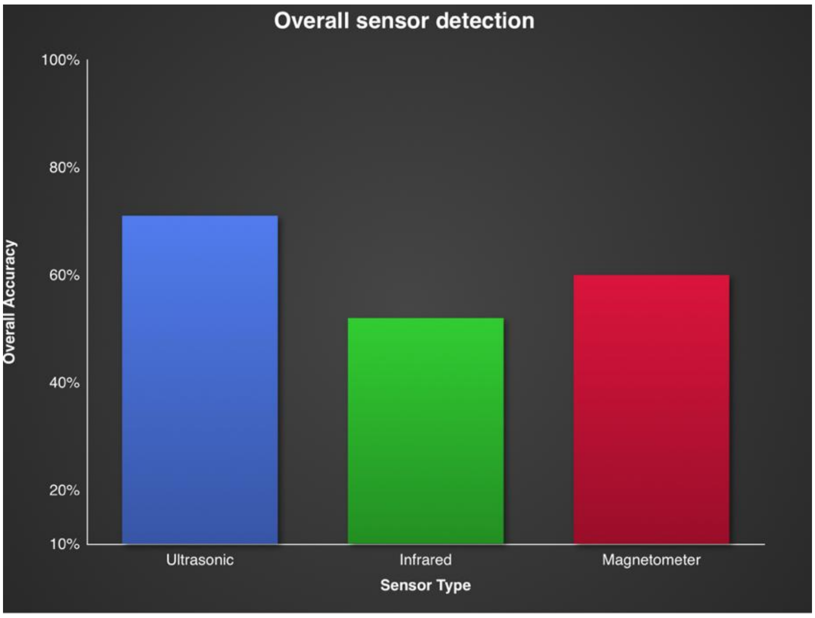
Sensor Type	Model	Cost	Principle
Ultrasonic	HCSRO4	10 AED	Sound wave reflection
Infrared	TCRT5000	18 AED	Light reflectance & absorption
Magnetometer	HMC5883L	19 AED	Magnetic field variation

4. Results

4.1 Sensor Detection Accuracy

Sensor	Sand	Clayey	Mixed gravel
Ultrasonic	89%	58%	66%
Infrared	74%	42%	39%
Magnetometer	96%	94%	91%

Overall Accuracy:



Depth wise analysis is essential to evaluate how detection reliability changes with increasing burial depth. To address this, detection success rates were calculated separately for shallow, medium, and deep burial conditions across all three sensing technologies:

Depth (cm)	Ultrasonic (%)	Infrared (%)	Magnetic (%)
2 to 3 cm	95%	88%	97%
5 to 6 cm	78%	60%	85%
8 to 10 cm	52%	35%	70%

The results clearly indicate a decrease in detection performance with increasing burial depth for all sensor types. This confirms that near surface artifacts are easily detectable regardless of sensing method. Ultrasonic and magnetic sensors continued to perform reasonably well, indicating better penetration capabilities in sub surface conditions. The infrared sensor showed the poorest performance, largely due to thermal signal attenuation with soil thickness. The magnetic sensor remained the most reliable, demonstrating its suitability for deeper metallic object detection.

5. Discussion

The results give a clearer understanding of how soil and depth influence sensor performance. Ultrasonic sensing worked well in sandy soil but struggled in clay, which supports findings from earlier research (Zhu, 2017). IR sensors had difficulty beyond very shallow depths, reflecting Parcak's (2019) observations. The magnetometer produced the strongest results, especially for metal artifacts, aligning with Bogomolov's (2019) conclusions. While these sensors cannot match the precision of GPR or other professional tools, they provide useful preliminary information and may help guide early excavation decisions. They also offer an affordable way for students and small teams to participate in archaeological discovery.

6. Conclusion

This study shows that inexpensive ultrasonic, IR, and magnetic sensors can detect shallow buried artifacts to a reasonable degree. Although their accuracy depends on soil conditions and artifact material, they can still support early stage surveys or educational projects. They should be viewed as complementary tools rather than replacements for professional archaeological equipment.

7. Future Work

Future studies could explore improved IR measurement techniques in changing environmental conditions, or combine multiple low cost sensors into a single robotic platform. Machine learning methods may also help interpret sensor data more accurately. Finally, researchers should consider the ethical and cultural implications of using robotic tools in archaeological settings.

8. References

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