

# Cutting-Edge Lead and Copper Detection: A COMSOL and Deep Learning Synergy

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# Cutting-Edge Lead and Copper Detection: A COMSOL and Deep Learning Synergy

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Civil and Environmental Engineering*

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## ABSTRACT

### Cutting-Edge Lead and Copper Detection: A COMSOL and Deep Learning Synergy

Zul Kazeem

This article presents an innovative approach for detecting lead and copper in buried pipes by integrating COMSOL Multiphysics simulations with machine learning techniques. The enhanced model includes a soil block to replicate real-world conditions and utilizes accelerometers for data acquisition. The collected data is processed and analyzed using a convolutional neural network (CNN) to accurately identify the presence of these metals. This method aims to offer a more efficient and non-invasive solution to metal detection in water systems.



# 1 Introduction

## 1.1 Background

The detection of lead and copper in water systems is not only crucial for public health but has gained renewed urgency with the Environmental Protection Agency's, <sup>1</sup>mandate to replace all lead pipes within the next 10 years. Lead contamination, in particular, poses severe health risks, including developmental delays, neurological impairments, and cardiovascular issues, especially in children and pregnant women. Similarly, elevated levels of copper can cause gastrointestinal distress and other health complications. Traditionally, detecting these metals in buried pipes has relied on invasive methods such as physical excavation and chemical testing, which are labor-intensive, time-consuming, and disruptive to water supply systems. Moreover, these methods often require significant resources and may not provide real-time monitoring capabilities.

In response to these challenges, water authorities and researchers are actively exploring innovative, non-invasive detection methods that can accurately identify lead and copper pipes without the need for extensive excavation. This pursuit has led to advancements in simulation software and machine learning techniques, offering promising avenues for enhancing detection capabilities.

This study addresses these pressing needs by proposing a novel approach that integrates COMSOL Multiphysics simulations with machine learning algorithms. By combining the detailed environmental simulations provided by COMSOL with the analytical power of machine learning, this method aims to provide a robust and efficient solution for detecting lead and copper in buried pipes.

49 The integration of COMSOL simulations allows for the creation of realistic mod-  
50 els that simulate the complex interactions between pipes, soil conditions, and  
51 other environmental factors. This includes adding a soil block to replicate the con-  
52 ditions in which pipes are buried, ensuring that the simulations closely mimic  
53 real-world scenarios. Furthermore, the use of accelerometers for data acquisition  
54 adds a layer of precision by capturing vibration and response data, which are criti-  
55 cal indicators for detecting the presence of metals based on their distinct physical  
56 properties.

57 In parallel, machine learning techniques, particularly convolutional neural net-  
58 works (CNNs), are employed to analyze the collected data and distinguish between  
59 lead and copper pipes. By training the CNN with a large dataset generated from  
60 COMSOL simulations, this study aims to enhance the accuracy and reliability of  
61 metal detection, thereby offering water authorities a practical tool for identifying  
62 and prioritizing pipe replacements.

## 63 **1.2 Motivation**

64 Lead and copper contamination in drinking water is a significant public health con-  
65 cern,<sup>2</sup>. Traditional detection methods involve physical inspections and chemical  
66 tests, which can be both time-consuming and disruptive. Recent advancements  
67 in simulation software and machine learning offer potential solutions to these  
68 challenges by providing non-invasive, accurate, and efficient detection methods.

69 Overall, this integrated approach not only addresses the immediate need for  
70 efficient metal detection in water systems but also sets the stage for future advance-  
71 ments in real-time monitoring and predictive maintenance strategies. As water  
72 utilities strive to comply with regulatory mandates and safeguard public health, in-  
73 novative solutions that blend simulation technologies with advanced analytics are  
74 poised to play a pivotal role in transforming how lead and copper contamination  
75 are managed in infrastructure systems.



## 76 2 Literature Review

77 Numerous studies have explored various methods for detecting lead and copper  
78 in water systems. Traditional methods include physical inspections and chemical  
79 testing, which have limitations in terms of cost and efficiency. Recent research  
80 has not focused on the use of simulation software, such as COMSOL Multiphysics,  
81 and machine learning algorithms to enhance detection capabilities. This is thus  
82 an integrating these technologies for practical applications remains an area of  
83 active research. The following article is structured as thus: the methodology that  
84 describes the process that was used for the experiment, the result that shows the  
85 output from the model, the discussion, and finally the conclusion.



## 86 3 Methods

### 87 3.1 Computational Methods

#### 88 3.1.1 Model

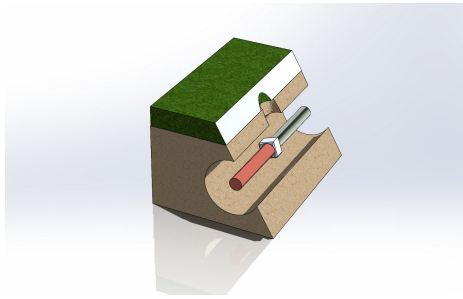
89 The simulation model consists of a soil block with uniform properties to replicate  
90 real-world conditions as much as possible but also to the extent that the model  
91 can allow. Steel was chosen as the material for the rod to be used with a hydraulic  
92 jack of 1000KN to ensure effective load transmission to the pipe.

93 The model is built using COMSOL Multiphysics using the solid mechanic model  
94 to simulate the effect of load on the pipe. The enhanced model was imported into  
95 Matlab, where random values were assigned to the pipe and load properties to sim-  
96 ulate various scenarios. This step was essential for generating a comprehensive  
97 dataset.

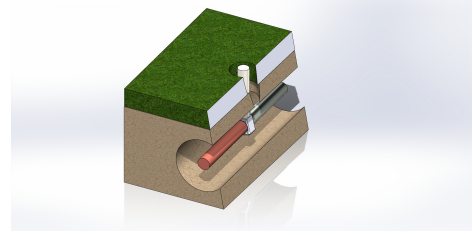
#### 98 3.1.2 Dataset Generation

99 Approximately 5000 datasets were generated to train the machine learning model.  
100 The large dataset is critical for improving the accuracy and reliability of the CNN  
101 used for detection.

$$\rho \left( \frac{\partial^2 u}{\partial t^2} \right) = \nabla \cdot \mathbf{S} + \mathbf{F}_v \quad (3.1)$$

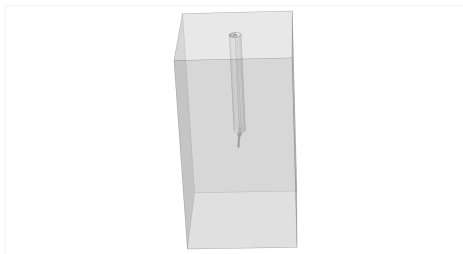


(a) Section of the buried Copper and Lead Pipe

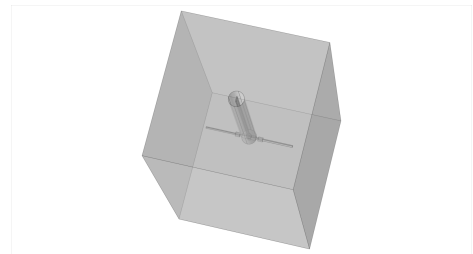


(b) Section of the buried Copper and Lead Pipe with steel rod

Figure 3.1. Section of the buried Copper and Lead Pipe with steel rod



(a) Side View



(b) Top View

Figure 3.2. Side and Top View of the Solid

102 **Data Categorization.** The generated data was separated into two categories: lead  
 103 and copper. This categorization enabled the CNN to learn the distinct characteris-  
 104 tics of each metal.

105 **Model Training.** The categorized data was used to train the CNN, aiming to develop  
 106 a robust detection system capable of identifying the presence of lead and copper  
 107 pipes that are buried without digging, thus saving cost.

## 108 4 Results

### 109 4.1 Computational Results

110 The integration of COMSOL simulations with machine learning resulted in a com-  
111 prehensive dataset representing various real-world scenarios. The CNN was trained  
112 with this data, showing promising accuracy in distinguishing between lead and  
113 copper based on the recorded acceleration readings.

Description	Point graph
X	Height
0	5.817362260551916E-20
1	5.817362260551916E-20
2	6.046114033737459E-20
3	5.076492751732623E-20
4	2.0101101950650483E-20
5	6.082783728329581E-20
6	6.082783728329581E-20
7	6.082783728329579E-20
8	1.3190892577783899E-20
9	4.7556868646350063E-20
10	4.755686864635008E-20
11	4.7556868646350033E-20

Table 4.1. Result of Lead and Copper after Sinusoidal load has been applied.

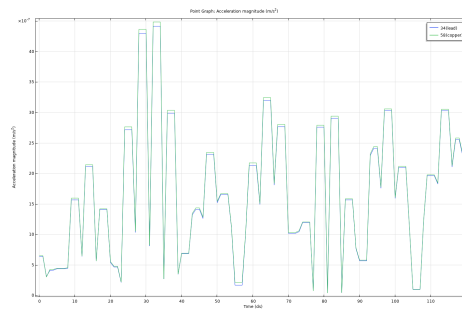


Figure 4.1. The graph that distinguishes between lead and copper.



## 114 5 Discussion

115     The combined use of COMSOL and machine learning demonstrated significant  
116 potential in improving the efficiency and accuracy of metal detection in water  
117 systems. The enhanced model, which includes a soil block and steel rod, effectively  
118 simulates real-world conditions. The generated dataset and subsequent training of  
119 the CNN highlight the feasibility of this approach. However, the process was slowed  
120 by the computational resources required, indicating a need for optimization in  
121 future work.

## 122 6 Conclusions

123 This study presents a novel method for detecting lead and copper in buried pipes  
124 by integrating COMSOL simulations with machine learning techniques. The en-  
125 hanced model and extensive dataset generation contribute to a more accurate and  
126 efficient detection system. Future work will focus on optimizing the computational  
127 aspects and further validating the model with real-world data.

## 128 7 Future Research

129 Future work on the detection of lead and copper using convolutional neural  
130 networks (CNNs) can expand in several directions. Firstly, integrating additional  
131 heavy metals such as mercury, arsenic, and cadmium into the detection model  
132 would broaden its applicability and usefulness. This expansion would involve gath-  
133 ering extensive datasets for these metals, followed by training and validating the  
134 model to ensure high accuracy and reliability. Additionally, improving the data  
135 collection techniques by incorporating advanced sensors and equipment could  
136 enhance the precision of the model. This improvement would involve collabora-  
137 tions with experts in sensor technology and data acquisition to develop a more  
138 robust and accurate detection system.

139 Another promising avenue is the development of a real-time monitoring sys-  
140 tem for detecting lead and copper in soil or water samples. Integrating IoT (Internet  
141 of Things) devices could enable remote monitoring and data collection, providing  
142 real-time updates and alerts for contamination levels. Moreover, exploring other  
143 machine learning algorithms such as Random Forest, SVM (Support Vector Ma-  
144 chines), or Deep Learning techniques like RNN (Recurrent Neural Networks) and  
145 LSTM (Long Short-Term Memory) networks could potentially improve the perfor-  
146 mance of the current CNN model. Extensive field testing and validation in various  
147 environments would be crucial to ensure the model's robustness and accuracy  
148 in real-world conditions. Collaborations with environmental agencies or institu-  
149 tions for large-scale validation studies could provide valuable insights and further  
150 enhance the model's reliability.

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