# Inverse Problems in Emerging Technology

Sara Bousba[1], Naila Marir[2]

[1]*LaMa Laboratory, Setif University 1, Setif, Algeria*
[2]*LIRE Laboratory, Constantine 2-Abdelhamid Mehri University, Constantine, Algeria*

Abstract
Inverse problems are a fundamental tool in many emerging technologies, enabling the recovery of important information from limited and noisy observations. In this survey, we aim to provide a comprehensive overview of the state of the art in inverse problems within emerging technologies. We focus on several important areas, including artificial intelligence, healthcare, machine learning, wireless communication, and energy modeling. We discuss the challenges and limitations of these inverse problems, as well as the recent advancements in their solution. Additionally, we highlight the significance of these inverse problems in each of these areas, and the potential impact they have on the development of new technologies. This survey provides a comprehensive overview of inverse problems in emerging technologies and serves as a valuable resource for researchers and practitioners in the field.

**Keywords**
Inverse problems, Emerging technologies, Machine learning, Modern and emerging systems

## 1. Introduction

Mathematical modeling is a powerful tool to solve problems emerging from the development of science and technology. The goal is frequently to gain quantities that can only be indirectly detected through measurements. For instance, a direct scan of the human body's interior is not conceivable. However, there exist methods that can obtain a scan by measuring the remaining intensity of X-rays that go through the body. Such indirect measurements are the result of processes, which are usually mathematically modeled and depend on the quantities we wish to find. This type of problem is called an inverse problem, involve calculating causal factors from observations [1, 2].

Meanwhile, emerging technologies, such as Artificial Intelligence (AI), Internet of Things (IoT), medical imaging, augmented reality, and energy, are particularly well-suited to the use of inverse problems due to their need for fast and accurate solutions to complex problems. An example of an emerging technology problem that can be posed as an inverse problem is in the field of medical imaging. Medical imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), allow doctors to visualize the internal structure of the human body. However, these images are often limited by factors such as noise and limited spatial resolution, which can reduce their accuracy and usefulness. One approach to improving the accuracy of these images is to treat the imaging problem as an inverse problem. In this approach, the goal is to estimate the internal structure of the body from the observed images,

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bousbasara@gmail.com (S. Bousba); naila.marir@univ-constantine2.dz (N. Marir)

while taking into account the various limitations and uncertainties associated with the imaging process.

The purpose of this survey is to provide an overview of the current state of the field of inverse problems in emerging technologies. It covers the key concepts and theories in inverse problems, as well as the various applications and challenges associated with the use of inverse problems in emerging technologies. This survey aims to provide a comprehensive and accessible resource for researchers and practitioners interested in the use of inverse problems in emerging technologies. By highlighting the importance of inverse problems in this field and the potential for continued growth and innovation, this survey can help to encourage further research and development in this area.

The reminder of this paper is organized as follows. Section 2 covers the background behind the inverse problems. Section 3 discuss the employed research method. Section 4 provides the finding of our survey. Future directions are given in section 4. Finally, the conclusion to our work is given to section 5.

## 2. Background

### 2.1. what is an inverse problems

Inverse problems involve the recovery of information about an unknown system or process from observations or measurements of its outputs. A problem is called inverse if the solution of the first part is required to formulate the second part. In other words, it is the technique of discovering causes from the information of their effects. This process is illustrated in Figure 1.

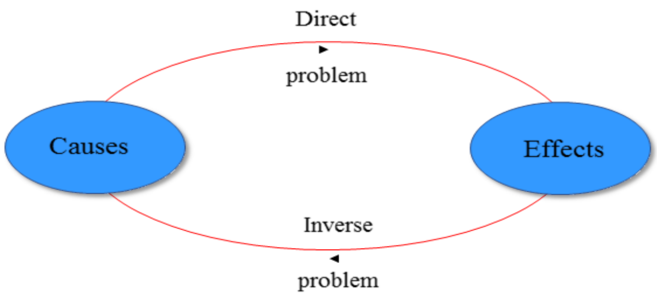


**Figure 1:** An illustration of forward and inverse problem.

Differentiation of data is a common example of an inverse problem. Given a set of data points that represent a function, the goal of the differentiation problem is to recover the derivative of the function from the data.

- Direct problem: let $x : [0.1] \to \mathbb{R}$ be a continuous function, compute

$$y(t) := \int_0^t x(s)\mathrm{d}s, \quad t \in [0, 1].$$

- Inverse Problem: Given a differentiable function $y : [0.1] \to \mathbb{R}$, determine $x := y'$

In practice, the differentiation of data is an important problem that arises in many fields. Accurately differentiating data is crucial for understanding the underlying dynamics and behavior of signals and systems, and for making informed decisions and predictions based on the data.

### 2.2. Well-Ill posed problems

The three conditions for a problem to be well-posed in the sense of Hadamard [3] are 1)Existence of a solution, 2)Uniqueness of solution and 3) Stability or continuity.

Mathematically, we formulate the notion of well-posedness [4] as follow:

Let $X$ and $Y$ be nomed spaces, $K : X \to Y$ a linear or nonlinear mapping. The equation $Kx = y$ is called well-posed if the following holds:

1. Existence of solution: For every $y \in Y$ there is at least one $x \in X$ such that $Kx = y$.
2. Uniqueness of a solution: For every $y \in Y$ there is at most one $x \in X$ with $Kx = y$.
3. Continuous dependence of the solution on the data: The solution $x$ depends continuously on $y$. That is, for every sequence $(x_n) \subset X$ with $Kx_n \to Kx \, (n \to \infty)$, it follows that $x_n \to x \, (n \to \infty)$.

These three conditions are important because they ensure that the problem is well-defined and that the solution is both predictable and stable. In many practical applications, it is essential to have a well-posed problem in order to make accurate predictions and ensure the stability of the solution. If any of the three condition are not satisfied, the problem is called improperly-posed or ill-posed.This ill-posed fundamental property makes inverse problems difficult and mathematically challenging. Ill-posed problems can pose significant difficulties when trying to solve them numerically, as small errors can result in arbitrarily large variations in the solution. To mitigate these difficulties, various regularization techniques can be used to stabilize the solution of an ill-posed problem. The idea behind regularization is to add additional information or constraints to the problem, in order to make it well-posed and to obtain a stable solution. This additional information is usually encoded as a penalty term in the objective function that is being minimized.

There are several types of regularization methods, including: 1) Tikhonov Regularization, 2) Morozov's discrepancy principle and Bayesian Regularization.

Each of these regularization methods has its own strengths and weaknesses, and the choice of method depends on the specific problem and the available data. In some cases, it may be beneficial to use a combination of regularization methods, or to adapt the regularization parameters based on the data.

## 3. Research method

This study aims to investigate the inverse problems in emerging technologies to identify innovative techniques that can help to address the challenges of existing methods. These advancements can help to improve the accuracy and reliability of systems and applications. This research employs a systematic review methodology known as mapping study or scoping [5], which is based on the following steps: A. Specifying research questions. B. Search strategy. C. Identification of primary studies. D. Data extraction. E. Threat to validity.

### 3.1. Research questions

The prime question that leads the investigation of inverse problems in emerging technologies is "How can we find the unknown inputs or parameters that produce a given output or observation in modern emerging systems?" This question is at the heart of our work, and drives the search for new and improved solutions and techniques. To pipeline this systematic mapping review this key question was split into two research questions:

1. What are the different emerging technologies that uses inverse problem solutions?
2. How this technologies defined their problems as an inverse problem?

The motivation behind understanding the different emerging technologies that use inverse problem solutions is to keep up-to-date with the latest developments and advancements in these fields. By having a clear understanding of the different technologies that use inverse problems, one can have a better appreciation of the diverse applications of this mathematical concept. This knowledge can be useful for researchers and engineers who are developing new algorithms and systems that use inverse problems. Overall, the motivation behind understanding the different emerging technologies that use inverse problem solutions is to stay informed and to have a deeper understanding of this important mathematical concept and its many applications.

### 3.2. Search strategy

The time frame covered by this study is from 2009 to 2022 inclusive. Additionally, the publications were re-searched using IEEEXplore, ACM Digital Library, Science Direct, and Google Scholar as the repositories.

## 4. Finding and discussions

In this section, we will try to answer the research questions posted in section 3.

1. What are the different emerging technologies that uses inverse problem solutions?

There are several emerging technologies that use inverse problem solutions, including:

**Artificial Intelligence**:

The importance of inverse problems in artificial intelligence is due to their ability to provide valuable insights and solutions to complex problems. By combining mathematical models and machine learning algorithms, AI systems can extract information from data, find hidden patterns and relationships, and make predictions and decisions in real-time [6, 7]. In [8], the authors presented an original contribution to the intersection of inverse problems and deep learning and proposed a new strategy for handling the regularization task in inverse problems. The approach taken in the paper is to leverage the inherent structure and information within the image data itself, rather than relying on external data or prior knowledge. The results showed that the deep neural network was capable of restoring images with high accuracy, even when the degradation was severe. The authors conclude that the Deep Image Prior is a powerful tool for solving inverse problems in computer vision, and can be applied to a wide range of image processing tasks such as denoising, super-resolution, and inpainting. They also suggest that the approach can be extended to other inverse problems in other fields, such as audio and speech processing.

The authors in [9], provides a review of the use of inverse problems in artificial intelligence, in which they discuss the different types of inverse problems and their applications in various areas such as image processing, pattern recognition, and computer vision. The authors highlight the importance of inverse problems in artificial intelligence and how they can be used to address some of the challenging problems in the field. They provide examples of how inverse problems have been used in various applications such as image restoration, image recognition, and object detection. They also discuss some of the limitations and challenges of using inverse problems in artificial intelligence and suggest future directions for research.

**Health care**:

In the field of healthcare, mathematical inverse problems have been used to address a variety of problems, such as image analysis and interpretation, disease diagnosis, and treatment planning [10, 11, 12, 13]. For example, medical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) use inverse problems to reconstruct images of internal organs and tissues based on measurements taken from the body. Additionally, inverse problems have been used in the analysis of biological signals, such as electroencephalography (EEG) and electrocardiography (ECG), to identify and diagnose diseases.

One example of a research paper in this area is [14]. This paper provides an overview of inverse problems in medical imaging and the various techniques used to address these problems, including MRI, CT, and ultrasound. The author also discusses the challenges and limitations of using inverse problems in medical imaging and the future directions for research in this area.

Overall, the use of mathematical inverse problems in healthcare has shown promise in the analysis and interpretation of medical data and has the potential to improve patient outcomes by providing more accurate and efficient diagnoses and treatments.

**Cybersecurity**:

The inverse problem in cybersecurity refers to the process of determining the cause of a security breach or vulnerability by analyzing its effects and symptoms. Anomaly and misuse detection in cybersecurity can be considered as an inverse problem, as it requires the identification of unusual and malicious behavior in a complex network system. To tackle these challenges, researchers are exploring a range of solutions, including machine learning algorithms, artificial intelligence, and data analytics, to develop more accurate and effective methods for detecting anomalies and misuses in cybersecurity. The inverse machine learning algorithm described in [15] appears to be a novel approach for addressing the problem of cyber anomaly detection. The authors model an anomaly detection system using an inverse model approach, which involves mapping observed network activity data to the underlying causes of anomalous behavior.

**Energy**:

The use of inverse problems in energy systems is becoming increasingly important as we look for more efficient and sustainable energy solutions. One example of the use of inverse problems in energy systems is in the field of renewable energy sources such as wind and solar power [16]. The goal of these systems is to maximize the energy output while minimizing the costs associated with energy production. However, this is a complex task, as the energy output of these systems is influenced by a variety of factors, including weather patterns, energy demand, and technological limitations. To tackle this challenge, researchers are using inverse problems to model and optimize the energy output of these systems. Another area where inverse problems are being used in energy systems is in the development of smart energy grids [16]. Smart energy grids are designed to help optimize the distribution and use of energy in a more efficient and sustainable manner. To achieve this goal, researchers are using inverse problems to model and optimize the energy demand patterns, energy distribution networks, and other aspects of smart energy grids.

2. How this technologies defined their problems as an inverse problem?

There are several examples of emerging technologies that have defined their problems as inverse problems:

**Intrusion detection systems:**

One common approach to intrusion detection is to treat the problem as an inverse problem. In this context, the inverse problem is to determine the underlying behavior patterns of the network or system, and to identify deviations from these patterns that may indicate an intrusion [17, 18, 15]. For example, one could consider a network traffic monitoring system, where the goal is to detect malicious activity by analyzing the incoming and outgoing traffic. This can be posed as an inverse problem, where the goal is to infer the presence of an intrusion based on observed network traffic patterns. The inverse problem is to reconstruct the network behavior patterns, taking into account the normal traffic patterns and any anomalies that might indicate an intrusion. The inverse problem can be formalized as a mathematical optimization problem, where the goal is to find the most likely intrusion scenario that fits the observed data. The solution to this inverse problem can then be used to identify and respond to potential intrusions in real-time.

**Internet of Things (IoT) systems:** Internet of Things (IoT) systems can encounter various problems that can be defined as inverse problems such as sensor calibration, localization [19], wireless channel estimation and fault detection and diagnosis [20]. One of the key challenges in IoT systems is the calibration of sensors, which is often necessary to obtain accurate and reliable measurements. The problem of sensor calibration can be defined as an inverse problem, where the goal is to estimate the parameters of the sensor model from the observed data. Another common problem in IoT systems is the localization of devices, which is the process of determining the physical location of a device based on its measurements. The problem of localization can be defined as an inverse problem, where the goal is to estimate the location of a device from the observed measurements and a model of the environment. These are some examples of how IoT problems can be defined as inverse problems, and the solutions to these inverse problems can help to improve the performance and reliability of IoT systems.

Overall, the use of inverse problems in modern emerging technologies provides a powerful tool for solving a wide range of problems where limited information is available. By formulating the problem as an inverse problem, the unknowns can be found through mathematical modeling and numerical algorithms, leading to improved solutions and better outcomes.

## 5. Future Directions

Inverse problems have been a topic of research for many years and have been used in various emerging technologies. As these technologies continue to evolve, the future directions of inverse problems are expected to focus on several key areas. Some of these directions include:

**Machine Learning and deep learning approaches**: In machine and deep learning, the future direction is expected to focus on developing more efficient and scalable inverse problems solutions that can handle large datasets, as well as new machine learning models that can be integrated with existing inverse problem algorithms. This integration is likely to lead to the development of new hybrid approaches that can address even more challenging problems, such as non-linear inverse problems and multi-modal inverse problems. In addition, we can expect to see more applications of inverse problems in machine learning, particularly in natural language processing.

**Real-time and big data applications**: The increasing demand for real-time and big data applications in emerging technology is driving research efforts to develop methods that can efficiently solve inverse problems in these contexts. In real-time applications, inverse problems can be used to process large amounts of data in real-time and provide quick, accurate results. Big data applications, on the other hand, can benefit from the use of inverse problems by leveraging the scalability and efficiency of inverse problem algorithms. Inverse problems can be used to process large amounts of data and extract meaningful insights, even when the data is noisy or incomplete. In both real-time and big data applications, the use of inverse problems can help to improve the accuracy of results and reduce the amount of time and resources required to process large amounts of data.

**Internet of Things (IoT)**: Inverse problems can be used to process and analyze the massive amounts of data generated by IoT devices, helping to uncover insights and make informed decisions. **Energy**: Inverse problems can be used to improve the efficiency and accuracy of energy systems, such as wind and solar power, by allowing engineers to better understand and model the underlying dynamics of these systems.

## 6. Conclusion

In conclusion, the use of inverse problems in emerging technologies is growing as more researchers and practitioners explore the potential applications of this field. Inverse problems are becoming increasingly relevant in areas such as artificial intelligence, internet of things, medical imaging, augmented reality, and energy, where they are being used to address problems such as model inversion, data analysis, and image and signal processing.

The future direction of the use of inverse problems in emerging technologies is likely to be driven by the need for fast and accurate solutions to complex problems in a wide range of applications. As new technologies emerge and existing ones continue to evolve, the use of inverse problems solutions is likely to play an increasingly important role in shaping the future of many industries and fields. Therefore, this survey highlights the importance of inverse problems in emerging technologies and the potential for continued growth and innovation in this field. By providing a comprehensive overview of the current state of the field, this survey can serve as a useful resource for researchers and practitioners interested in the use of inverse problems in emerging technologies.

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