Using Mobile Phone Sensors to Identify Underground Pipes: A Narrative Review of Modern Mobile Phone Applications

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Abstract

Smartphones are equipped with a variety of sensors that enable them to perform a wide range of functions, including compass, GPS, gyroscope, GIS, and augmented reality (AR). In this article, we will explore how these sensors can be used in combination to virtually see underground pipes, such as water and gas pipes. By leveraging the precise location and orientation capabilities of GPS and the compass, and the ability of the gyroscope to detect changes in orientation, smartphones can provide a realistic and accurate representation of underground pipes in real time. Additionally, by using AR technology, this information can be overlaid onto the user's view of the real world, enabling them to see underground pipes as if they were visible above ground.

Keywords: Mobile App; GIS; Augmented Reality; Sensor; Pipeline

Introduction

Underground pipes, such as water and gas pipes, are an integral part of our infrastructure. (Lotz & Hough, 2021) They are responsible for delivering essential utilities such as clean water, heat, and electricity to our homes and businesses. These pipes are typically buried underground and are not visible to the naked eye, making them difficult to locate and access for maintenance or repair purposes. This can be a challenge for utility workers, engineers, and other professionals who need to locate and access these pipes for various purposes, such as replacing or repairing damaged pipes, or installing new ones.

In recent years, technology has progressed to the point where it is now possible to virtually see underground pipes using smartphones. This is achieved through the combination of several sensors and technologies, including compass, GPS, gyroscope, GIS, and augmented reality (AR). Compass is a device that determines direction based on the Earth's magnetic field (Lowrie & Fichtner, 2020). GPS, or Global Positioning System, is a satellite-based navigation system that provides location and time information (Morton, Van Diggelen, Spilker & Parkinson, 2020). Gyroscope is a device that measures angular velocity and is used to stabilize images (Gerste, 2019). GIS, or Geographic Information System, is a system designed to capture, store, manipulate, analyze, and present spatial data (Senapathi, Viswanathan & Chung, 2019). AR, or Augmented Reality, is a technology that superimposes computer-generated images onto the user's view of the real world (Pangilinan, Lukas & Mohan, 2019).

By combining these technologies, it is possible to obtain a realistic and accurate representation of underground pipes in real time, and to display virtual markers or labels indicating the location and type of pipes overlaid onto the user's view of the real world. This can be a valuable tool for utility workers, engineers, and other professionals who need to locate and access underground pipes for maintenance or repair purposes, as it can help them to locate and identify the pipes, they are looking for more easily and accurately.

The use of compass, GPS, gyroscope, GIS, and AR in smartphones for the purpose of virtually seeing underground pipes offers several benefits. It can improve safety by allowing users to locate underground pipes more easily, and to avoid disturbing or damaging them. This can prevent accidents and injuries, and reduce the risk of damaging the pipes, which can lead to costly repairs and disruptions in service. It can also increase efficiency by reducing the time and effort required to locate and access underground pipes. This can save resources and money and allow for quicker and more efficient repairs or installations. Additionally, it can enhance the overall user experience by providing a more convenient and intuitive way of accessing and interacting with this information.

In this article, we will delve into the technologies used to virtually see underground pipes in smartphones, and how they work together to achieve this goal. We will examine the principles and applications of compass, GPS, gyroscope, GIS, and AR, as well as the advantages and disadvantages of each technology in this context. Finally, we will look at some real-world examples of the use of these technologies for virtually seeing underground pipes and consider the future potential of this application.

Compass

A compass is a device that determines direction based on the Earth's magnetic field (Lowrie & Fichtner, 2020). It consists of a magnetized needle or pointer that aligns itself with the Earth's magnetic field, and a circular scale marked with the cardinal directions (north, south, east, west) that allows the user to determine the direction they are facing. Compasses have been used for centuries for navigation, and they continue to be an essential tool for outdoor enthusiasts, military personnel, and others who need to know their direction to find their way.

In smartphones, compass is often used in combination with other sensors and technologies, such as GPS, gyroscope, and AR, to provide location and orientation information. When the compass sensor in a smartphone detects the Earth's magnetic field, it can determine the direction the phone is facing relative to magnetic north. This information can be used to orient the phone's display, or to display virtual markers or labels that are anchored to the real world.

Fig. 1 Compass sensor on smartphones.

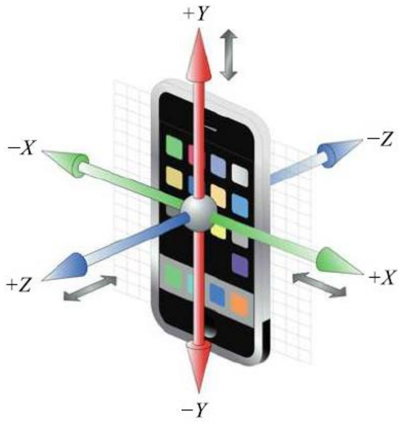


Fig. 2 Accelerometer axes on smartphones

For example, a smartphone app that uses compass, GPS, and AR to virtually see underground pipes might display a virtual map of the pipes overlaid onto the user's view of the real world. As the user moves their phone, the compass sensor would detect the change in direction and update the orientation of the map accordingly, so that it always appears to be aligned with the real world. This can make it easier for the user to locate and identify the pipes they are looking for, as the map would always be oriented in the same direction as the real world.

One advantage of using compass in smartphones for the purpose of virtually seeing underground pipes is that it can provide orientation information even when the phone is not connected to a network or satellite. This can be useful in situations where GPS or other network–

dependent technologies are not available, such as when the user is in a location with poor or no signal coverage.

However, there are also some limitations to using compass in this context. For example, compass can be affected by interference from nearby metallic objects or electronic devices, which can cause the needle or pointer to deviate from its correct position. This can make it difficult for the compass to accurately determine the direction the phone is facing, which can affect the accuracy of the orientation information displayed by the app. Additionally, compass is sensitive to the Earth's magnetic field, which can vary from place to place. This means that the accuracy of the compass may be affected by the location of the user, and it may be less accurate in some places than in others.

GPS

GPS, or Global Positioning System, is a satellite-based navigation system that provides location and time information to users anywhere on or near the Earth's surface. It was developed by the U.S (Peabody, 2010). Department of Defense in the 1970s, and it is now used by millions of people around the world for a wide range of applications, including navigation, tracking, and mapping.

How GPS works

GPS works by using a network of satellites orbiting the Earth to triangulate the position of a user's device. The user's device, such as a smartphone or GPS receiver, receives signals from multiple satellites, and it uses the time delay of these signals to determine the distance from each satellite. By combining the distances from multiple satellites, the device can calculate its position with high accuracy. Minimum of three satellite signal needed to allow GPS system to find the location(El-Rabbany, 2002) as shown if Fig.1.

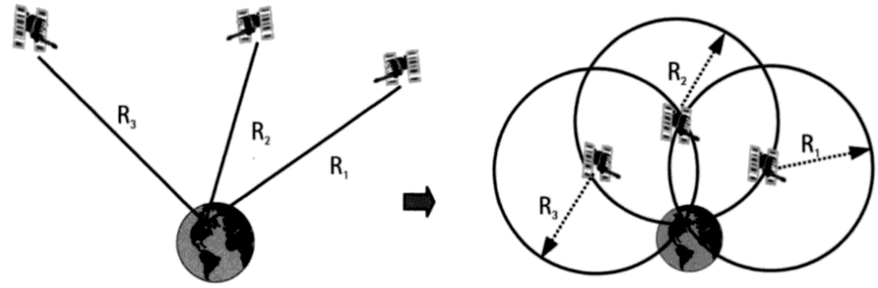


Fig.3 GPS System

Benefits of GPS in smartphones

In smartphones, GPS is often used in combination with other sensors and technologies, such as compass, gyroscope, and AR, to provide location and orientation information. One of the main benefits of using GPS in smartphones for the purpose of virtually seeing underground pipes is that it can provide precise location information to the user. This can be useful for locating and accessing specific pipes, or for navigating to a specific location where pipes are located.

GPS can also be used to improve the accuracy of the orientation information provided by the compass and gyroscope. By combining the location information provided by GPS with the orientation information provided by the other sensors, the smartphone can more accurately determine the direction the user is facing and display virtual markers or labels that are anchored to the real world.

Limitations of GPS in smartphones

There are also some limitations to using GPS in smartphones for the purpose of virtually seeing underground pipes. One of the main limitations is that GPS requires a clear view of the sky in order to receive signals from the satellites. This means that it may not work well or at all in certain situations, such as when the user is inside a building, under heavy tree cover, or in a location with tall structures or buildings that block the view of the sky.

Another limitation of GPS is that it can be affected by interference from other sources, such as radio frequency (RF) noise, or by the presence of multiple devices in the same location. This can cause the GPS signals to be disrupted or distorted, which can affect the accuracy of the location information. Additionally, GPS can be impacted by factors such as the atmospheric conditions and the geometry of the satellites, which can also affect the accuracy of the location information.

Finally, it is worth noting that GPS consumes a significant amount of power, and it can drain the battery of a smartphone quickly if it is used continuously. This can be a concern for users who need to use GPS for extended periods of time, or who may not have access to a power source to recharge their phone.

Additional considerations

Another consideration when using GPS in smartphones is that it can be affected by interference from other sources, such as radio frequency (RF) noise, or by the presence of multiple devices in the same location (Morton, Van Diggelen, Spilker & Parkinson, 2020). This can cause the

GPS signals to be disrupted or distorted, which can affect the accuracy of the location information. Additionally, GPS can be impacted by factors such as the atmospheric conditions and the geometry of the satellites, which can also affect the accuracy of the location information.

Finally, it is worth noting that GPS consumes a significant amount of power, and it can drain the battery of a smartphone quickly if it is used continuously. This can be a concern for users who need to use GPS for extended periods of time, or who may not have access to a power source to recharge their phone.

In summary, GPS is a powerful and useful tool for providing location and orientation information in smartphones. However, it is important to be aware of its limitations and potential sources of interference, and to take steps to minimize their impact on the accuracy of the information provided.

Gyroscope

A gyroscope is a device that measures angular velocity and can be used to determine orientation (Qiao et al., 2019). It consists of a spinning wheel or disc that is mounted on a set of gimbals, which allow it to rotate freely in any direction. When the device is rotated, the gyroscope’s spinning wheel resists the change in orientation, and the amount of resistance can be used to calculate the angular velocity and orientation of the device.

How gyroscopes work

Gyroscopes work by exploiting the principle of angular momentum, which states that a spinning object will tend to maintain its orientation unless acted upon by an external force. This means that when a device with a gyroscope is rotated, the gyroscope's spinning wheel will resist the change in orientation, and the amount of resistance will depend on the angular velocity of the device.

By measuring the amount of resistance, the gyroscope can determine the angular velocity and orientation of the device. This information can be used to orient the device’s display, or to display virtual markers or labels that are anchored to the real world (Hamza-Lup, 2019).

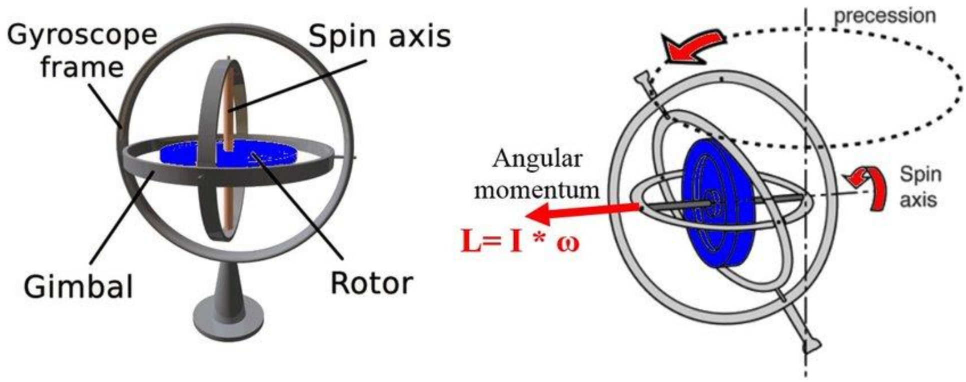


Fig.4 Gyroscope

Benefits of gyroscopes in smartphones

In smartphones, gyroscopes are often used in combination with other sensors and technologies, such as compass, GPS, and AR, to provide orientation and motion information (Zhang, Han, Hao & Lv, 2016). One of the main benefits of using gyroscopes in smartphones for the purpose of virtually seeing underground pipes is that they can provide real-time orientation information to the user (Zhang et al., 2016). This can be useful for navigating through complex environments, or for identifying and accessing specific pipes.

Gyroscopes can also be used to improve the accuracy of the orientation information provided by the compass and GPS (Kappi, Syrjarinne & Saarinen, 2001). By combining the orientation information provided by the gyroscope with the location information provided by GPS, the smartphone can more accurately determine the direction the user is facing and display virtual markers or labels that are anchored to the real world (Su, Tong & Ji, 2014).

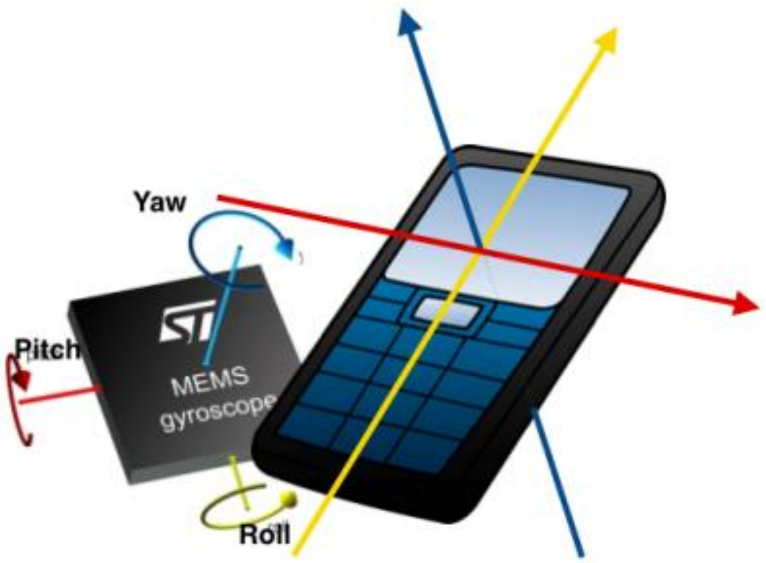


Fig.5 Three axes of gyroscope on smartphones

Limitations of gyroscopes in smartphones

There are also some limitations to using gyroscopes in smartphones for the purpose of virtually seeing underground pipes (Kim, Lee, Lim, Seo & Kang, 2014). One limitation is that gyroscopes can be affected by drift, which means that the orientation information they provide may drift over time. This can be caused by factors such as temperature changes, mechanical wear, or the accumulation of dirt or debris on the gyroscope's spinning wheel.

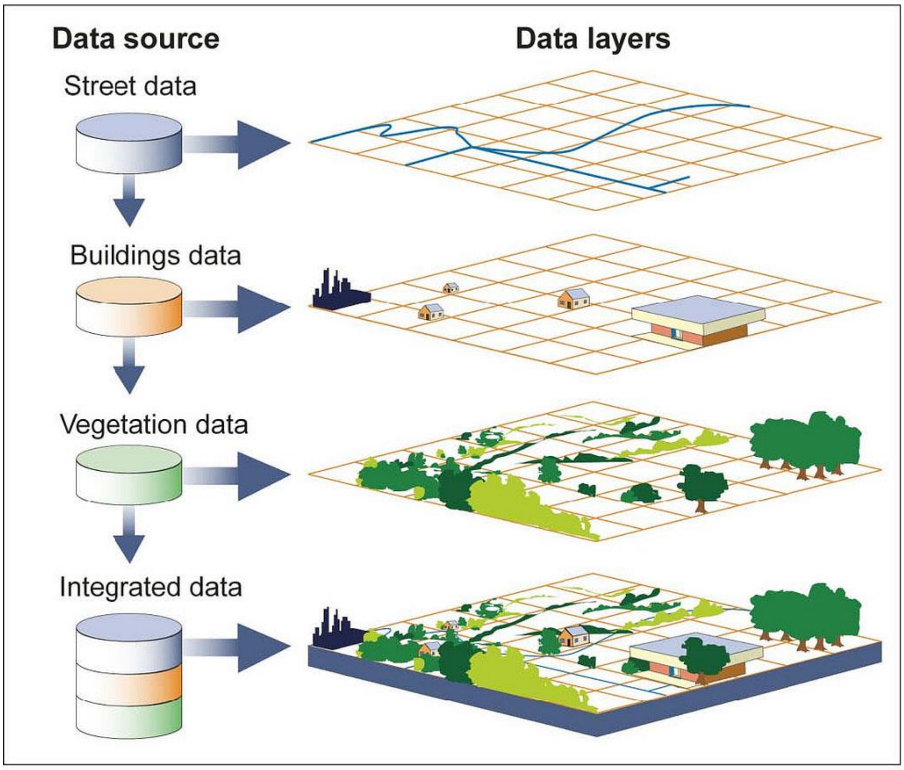
Another limitation of gyroscopes is that they are sensitive to external forces, such as acceleration, vibration, or shock. This means that they may not work well in environments where these forces are present, or where the device is subjected to sudden or extreme changes in orientation.

Finally, it is worth noting that gyroscopes can consume a significant amount of power, and they can drain the battery of a smartphone quickly if they are used continuously. This can be a concern for users who need to use the gyroscope for extended periods of time, or who may not have access to a power source to recharge their phone.

In summary, gyroscopes are a useful tool for providing orientation and motion information in smartphones. However, it is important to be aware of their limitations and potential sources of drift, and to take steps to minimize their impact on the accuracy of the information provided.

GIS

GIS, or Geographic Information System, is a technology that is used to capture, store, manipulate, analyze, and display spatial data (Bhat, Shah & Ahmad, 2011). It consists of a set of tools and techniques that are used to create, manage, and analyze geographic data, and to display the results in a variety of formats, including maps, charts, and reports.



Source: GAO.

Fig.6 GIS System (Nationalgeographic)

What is GIS and how does it work?

GIS is a powerful tool for working with geographic data, as it allows users to analyze and display spatial data in a variety of ways. It consists of a set of software and hardware tools that are used to create, manage, and analyze geographic data, and to display the results in a variety of formats, including maps, charts, and reports (Chrisman, 1999).

GIS works by storing geographic data in a database, which can be queried and analyzed using a set of tools and techniques. The data can be in the form of points, lines, polygons, or rasters, and can include information such as location, attribute data, and spatial relationships.

Types of data used in GIS

There are several types of data that are used in GIS, including:

1) Vector data: Vector data consists of points, lines, and polygons that represent the location and shape of geographical features. It is often used to represent data such as roads, buildings, and land parcels.

2) Raster data: Raster data consists of a grid of cells that are used to represent continuous surfaces, such as land elevation or satellite imagery. Each cell in the grid contains a value that represents the attribute of the feature being represented.

3) Attribute data: Attribute data consists of information about the features being represented in the GIS, such as the name, type, or other characteristics of the feature. It is often stored in a database table and linked to the spatial data in the GIS.

4) Spatial data: Spatial data consists of information about the location and shape of geographical features, and includes data such as coordinates, projections, and spatial relationships.

Benefits of GIS in smartphones

There are several benefits to using GIS in smartphones for the purpose of virtually seeing underground pipes. One of the main benefits is that it allows users to access and analyze geographic data in real-time, which can be useful for navigating complex environments or for identifying and accessing specific pipes.

GIS also allows users to display and analyze the data in a variety of formats, including maps, charts, and reports, which can be helpful for understanding the spatial relationships and patterns in the data.

Limitations of GIS in smartphones

There are also some limitations to using GIS in smartphones for the purpose of virtually seeing underground pipes. One limitation is that GIS requires a significant amount of data storage and processing power, which may not be available on all smartphones. This can be a concern for users who need to store and analyze large amounts of data, or who may not have access to a device with sufficient processing power.

Another limitation of GIS is that it requires a reliable internet connection in order to access and update the data. This can be a concern for users who may not have access to a reliable connection, or who may need to use the GIS in areas with limited or no internet coverage.

Finally, it is worth noting that GIS can be complex and require specialized skills to use effectively. This can be a barrier for users who may not have the necessary training or experience to use the GIS software and tools.

In summary, GIS is a powerful tool for working with geographic data, but it is important to be aware of its limitations and the resources it requires in order to be used effectively.

Augmented Reality

Augmented Reality (AR) is a technology that is used to superimpose computer-generated images and information onto the real world, in real-time (Chang, Morreale & Medicherla, 2010). It is often used in applications such as gaming, education, and entertainment, and it has the potential to revolutionize the way we interact with the world around us.

What is Augmented Reality and how does it work?

Augmented Reality (AR) is a technology that allows users to see and interact with virtual objects and information in the real world, in real-time. It works by using sensors and cameras to capture the real-world environment, and then superimposing computer-generated images and information onto the captured image. The resulting image is then displayed on a screen or through a headset, allowing the user to see and interact with the virtual objects as if they were part of the real world.

There are several types of AR, including:

1) Projection-based AR: This type of AR uses a projector to display the virtual objects onto a surface, such as a table or a wall.

2) Superimposition-based AR: This type of AR uses a camera to capture the real-world environment, and then superimposes the virtual objects onto the captured image.

3) Marker-based AR: This type of AR uses a specific image or pattern, known as a marker, to trigger the display of the virtual objects. The marker can be a physical object, such as a QR code, or it can be a digital image displayed on a screen.

Benefits of Augmented Reality in smartphones

There are several benefits to using Augmented Reality in smartphones for the purpose of virtually seeing underground pipes (Nincarean, Alia, Halim & Rahman, 2013). One of the main benefits is that it allows users to see and interact with virtual objects in the real world, which can be helpful for understanding complex systems or for visualizing the location and orientation of underground pipes.

Augmented Reality also has the potential to improve the accuracy and efficiency of tasks such as pipe inspection and maintenance, as it allows users to access and analyze data in real-time, without the need for physical access to the pipes. (Piroozfar, Judd, Boseley, Essa & Farr, 2021)

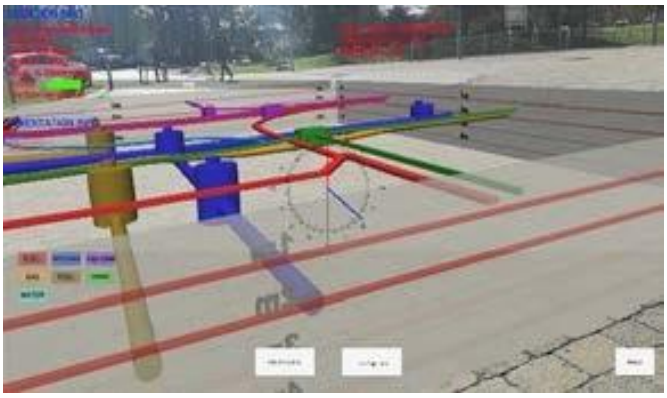


Fig.7 Virtual pipes view

Limitations of Augmented Reality in smartphones

There are also some limitations to using Augmented Reality in smartphones for the purpose of virtually seeing underground pipes. One limitation is that it requires a device with a high-quality camera and display, as well as processing power and memory to support the AR software. This can be a concern for users who may not have access to a device with these capabilities, or who may not have the resources to upgrade their device.

Another limitation of Augmented Reality is that it requires a reliable internet connection in order to access and update the virtual objects and information (Information Resources Management Association, 2018). This can be a concern for users who may not have access to a reliable connection, or who may need to use the AR in areas with limited or no internet coverage.

Finally, Augmented Reality can be complex and require specialized skills to use effectively. This can be a barrier for users who may not have the necessary training or experience to use the AR software and tools.

In summary, while Augmented Reality has the potential to revolutionize the way we interact with the world around us, it is important to be aware of its limitations and the resources it requires in order to be used effectively.

Applications of Augmented Reality in smartphones

There are several potential applications for Augmented Reality in smartphones for the purpose of virtually seeing underground pipes. Some examples include:

1) Pipe inspection and maintenance: Augmented Reality can be used to visualize the location and orientation of underground pipes, as well as to access and analyze data in real-time, without

the need for physical access to the pipes. This can improve the accuracy and efficiency of tasks such as inspection and maintenance.

2) Training and education: Augmented Reality can be used to create interactive, immersive learning experiences, allowing users to visualize and understand complex systems in a more intuitive way.

3) Safety and emergency response: Augmented Reality can be used to provide real-time information and guidance in the event of an emergency, such as a gas leak or water main break.

Future developments in Augmented Reality for smartphones

There are several potential developments in Augmented Reality that could enhance its use in smartphones for the purpose of virtually seeing underground pipes. Some examples include:

1) Improved hardware: As smartphones become more powerful and sophisticated, the capabilities of AR applications are likely to increase. This could include higher-quality cameras and displays, as well as faster processing speeds and larger memory capacity.

2) Enhanced accuracy: Improved algorithms and sensors could allow for more accurate and realistic AR experiences, making it easier for users to visualize and interact with the virtual objects.

3) Greater integration with other technologies: Augmented Reality could be integrated with other technologies, such as GPS and GIS, to create more comprehensive and accurate virtual representations of the real world.

Overall, the future of Augmented Reality in smartphones looks bright, and it has the potential to revolutionize the way we interact with the world around us. As more and more organizations and industries adopt AR technology, we can expect to see a wide range of exciting new applications and uses for this powerful technology.

Use of compass, GPS, gyroscope, and AR in smartphones for virtually seeing underground pipes

In this section, we will explore how the combination of compass, GPS, gyroscope, and AR technology in smartphones can be used to virtually see underground pipes.

How does the compass aid in virtually seeing underground pipes?

The compass, or magnetometer, is a sensor that measures the strength and direction of the earth's magnetic field. In smartphones, the compass is used to determine the device's orientation and to enable features such as location-based services and map navigation.

In the context of virtually seeing underground pipes, the compass can be used to provide a sense of direction and orientation, helping the user to visualize the location and orientation of the pipes relative to their own position.

How does GPS aid in virtually seeing underground pipes?

Global Positioning System (GPS) is a satellite-based navigation system that provides location and time information in all weather conditions, anywhere on or near the earth. In smartphones, GPS is used to enable features such as map navigation and location-based services.

In the context of virtually seeing underground pipes, GPS can be used to accurately locate the position of the device, as well as to provide real-time updates on the location of the pipes. This can be especially useful in cases where the pipes are in remote or hard-to-reach areas.

How does the gyroscope aid in virtually seeing underground pipes?

The gyroscope is a sensor that measures the angular velocity of the device, or the rate at which it rotates around its own axis. In smartphones, the gyroscope is used to enable features such as virtual reality and motion-based gaming, as well as to improve the accuracy of the compass.

In the context of virtually seeing underground pipes, the gyroscope can be used to track the orientation and movement of the device, allowing the user to visualize the pipes in 3D space and to manipulate the virtual objects with greater precision.

How does AR technology aid in virtually seeing underground pipes?

As described earlier, Augmented Reality (AR) is a technology that is used to superimpose computer-generated images and information onto the real world, in real-time. In the context of virtually seeing underground pipes, AR technology can be used to create a virtual representation of the pipes and the surrounding environment, allowing the user to see and interact with the pipes as if they were physically present.

AR technology can also be used to access and analyze data in real-time, without the need for physical access to the pipes. This can be especially useful for tasks such as inspection and maintenance, as it allows the user to identify and address issues more quickly and efficiently.

Advantages of using compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes.

The combination of compass, GPS, gyroscope, and AR technology in smartphones offers several advantages for virtually seeing underground pipes. Some of the main advantages include:

1) Enhanced accuracy: By using multiple sensors and technologies, it is possible to create a more accurate and realistic representation of the pipes and the surrounding environment.

2) Improved efficiency: The ability to visualize and interact with the pipes in real-time can significantly improve the efficiency of tasks such as inspection and maintenance.

3) Increased safety: By using AR technology to access and analyze data without physically accessing the pipes, it is possible to reduce the risk of injury and accidents.

4) Cost savings: Using AR technology to virtually see underground pipes can reduce the need for physical access to the pipes, potentially leading to cost savings in terms of time and resources.

5) Greater accessibility: By making it possible to access and visualize the pipes remotely, AR technology can improve the accessibility of the pipes, especially in cases where they are in remote or hard-to-reach areas.

In summary, the combination of compass, GPS, gyroscope, and AR technology in smartphones offers many advantages for virtually seeing underground pipes and has the potential to revolutionize the way we interact with and manage these important infrastructure assets.

Case studies of using compass, GPS, gyroscope, and AR in smartphones for virtually seeing underground pipes:

Case study 1 Virtual inspection of water pipes (Liu & Kleiner, 2013)

In this case study, we will look at how a smartphone app was developed to allow utilities workers to virtually inspect water pipes using compass, GPS, gyroscope, and AR technology. The app was designed to work in conjunction with sensors that were installed inside the water pipes. These sensors collected data on the condition of the pipes, including corrosion, leaks, and pressure.

Using the app, utilities workers were able to visualize the location and condition of the pipes in real-time, as they walked along the pipes. The app displayed an AR overlay on the smartphone’s camera, showing the location and condition of the pipes relative to the worker's position and orientation.

The app also included features such as map navigation, location tracking, and data visualization, which allowed the workers to inspect the pipes efficiently and effectively.

This case study demonstrates how compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground pipes, in this case, water pipes, in a safe and efficient manner.

Case study 2 Virtual mapping of gas pipes (Choi & Ryew, 2002)

In this case study, we will look at how a smartphone app was developed to allow utilities workers to virtually map gas pipes using compass, GPS, gyroscope, and AR technology.

The app was designed to work in conjunction with sensors that were installed on the gas pipes. These sensors collected data on the location and attributes of the pipes, such as diameter, material, and age.

Using the app, utilities workers were able to visualize the location and attributes of the pipes in real-time, as they walked along the pipes. The app displayed an AR overlay on the smartphone's camera, showing the location and attributes of the pipes relative to the worker's position and orientation.

The app also included features such as map navigation, location tracking, and data visualization, which allowed the workers to map the pipes efficiently and effectively.

This case study demonstrates how compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground pipes, in this case, gas pipes, and to collect and analyze data about the pipes.

Case study 3 Virtual training for emergency response (Chen, Rebolledo-Mendez, Liarokapis, de Freitas & Parker, 2008)

In this case study, we will look at how a smartphone app was developed to allow emergency responders to virtually train for situations involving underground pipes using compass, GPS, gyroscope, and AR technology.

The app was designed to simulate real-world scenarios involving underground pipes, such as gas leaks or water main breaks. The app used GPS to locate the user in a virtual environment, and displayed an AR overlay on the smartphone’s camera, showing the location and attributes of the virtual pipes relative to the user's position and orientation.

Using the app, emergency responders were able to practice responding to and mitigating emergencies involving underground pipes in a safe and controlled environment. The app also allowed them to familiarize themselves with the location and attributes of real-world pipes in their jurisdiction, using GIS data.

This case study demonstrates how compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground pipes and to train for emergencies involving underground pipes.

Case study 4 Virtual maintenance of sewer pipes (Lawson & Pretlove, 1998)

The app was designed to work in conjunction with sensors that were installed inside the sewer pipes. These sensors collected data on the condition of the pipes, including blockages, leaks, and infiltration.

Using the app, utilities workers were able to visualize the location and condition of the pipes in real-time, as they walked along the pipes. The app displayed an AR overlay on the smartphone's camera, showing the location and condition of the pipes relative to the worker's position and orientation.

The app also included features such as map navigation, location tracking, and data visualization, which allowed the workers to maintain the pipes efficiently and effectively.

This case study demonstrates how compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground pipes, in this case, sewer pipes, and to identify and address issues with the pipes.

Case study 5 Virtual mapping of underground utilities (Fenais, Ariaratnam & Smilovsky, 2020)

In this case study, we will look at how a smartphone app was developed to allow contractors and utilities workers to virtually map underground utilities using compass, GPS, gyroscope, and AR technology.

The app was designed to work in conjunction with sensors that were installed on various underground utilities, such as electrical cables, fiber optic cables, and water pipes. These sensors collected data on the location and attributes of the utilities, such as depth, material, and owner.

Using the app, contractors and utilities workers were able to visualize the location and attributes of the utilities in real-time, as they walked along the utilities. The app displayed an AR overlay on the smartphone's camera, showing the location and attributes of the utilities relative to the worker’s position and orientation.

The app also included features such as map navigation, location tracking, and data visualization, which allowed the workers to map the utilities efficiently and effectively.

This case study demonstrates how compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground utilities and to collect and analyze data about the utilities.

In conclusion, the case studies discussed in this section demonstrate the various ways in which compass, GPS, gyroscope, and AR technology can be used in smartphones to virtually see underground pipes. From inspection and mapping to training and maintenance, these technologies offer a wide range of benefits and applications in the field of underground pipes.

Challenges and limitations of using compass, GPS, gyroscope, and AR in smartphones for virtually seeing underground pipes:

Accuracy and precision

One of the challenges of using compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes is the accuracy and precision of the data collected and displayed.

Compass, GPS, and gyroscope sensors in smartphones are subject to various sources of error, such as interference from external magnetic fields, atmospheric conditions, and satellite geometry. These errors can affect the accuracy and precision of the data collected by the sensors, which can in turn affect the accuracy and precision of the AR overlay displayed on the smartphone's camera.

Data connectivity

Another challenge of using compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes is data connectivity.

To collect and transmit data from the sensors to the smartphone, and to display the AR overlay on the smartphone's camera, a stable and reliable data connection is required. In some cases, such as in underground or remote locations, the data connection may be weak or non-existent, which can hinder the performance of the app and the AR experience.

Battery life

The use of compass, GPS, gyroscope, and AR technology in smartphones can also impact the battery life of the device.

These sensors and technologies require a significant amount of power to operate, and the use of the app and the AR overlay can significantly drain the battery of the smartphone. This can be a challenge in situations where a long battery life is required, such as in long inspections or mapping sessions.

Hardware and software compatibility

The use of compass, GPS, gyroscope, and AR technology in smartphones also depends on the hardware and software compatibility of the device.

Not all smartphones are equipped with these sensors and technologies or are compatible with the app and the AR overlay. This can limit the use of these technologies to certain devices and may require users to purchase or upgrade to a compatible device in order to use the app and the AR overlay.

User experience

Another challenge of using compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes is the user experience.

The app and the AR overlay may require a certain level of skill and knowledge to operate and may have a learning curve for users who are not familiar with these technologies. In addition, the app and the AR overlay may have user interface (UI) and user experience (UX) issues that can affect the usability and enjoyment of the app and the AR overlay.

Cost

The use of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes may also be limited by cost (Zhang et al., 2016).

The development and maintenance of the app and the infrastructure required to support the app and the AR overlay (such as sensors and data servers) can be expensive. In addition, the purchase or upgrade of a compatible smartphone may also be a cost factor for users.

However, it is important to consider the potential cost savings and benefits that may result from using these technologies. For example, the use of an app for virtually seeing underground pipes may reduce the need for physical inspections, which can be time-consuming and costly. It may also allow for more accurate and efficient identification and repair of problems, which can reduce the likelihood of costly repairs or disruptions in service.

Overall, the cost of using compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes will depend on the specific circumstances and needs of the user.

Legal and regulatory issues

The use of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes may also be subject to legal and regulatory issues.

For example, there may be privacy and data protection concerns related to the collection and use of location and other personal information by the app. There may also be issues related to the accuracy and reliability of the information provided by the app, and the liability of the app developer and the user in case of errors or accidents.

In addition, there may be legal and regulatory requirements related to the maintenance and repair of underground pipes, such as obtaining permits and following safety and environmental standards. These requirements may vary by jurisdiction and may impact the use of the app.

It is important for users of the app to be aware of and comply with these legal and regulatory issues to avoid potential risks or consequences.

Conclusion and future developments

In conclusion, the use of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes offers a range of potential benefits and challenges. The technology has the potential to improve the safety, efficiency, and user experience of inspecting and maintaining underground pipes, but it also involves cost, legal and regulatory issues, and technical limitations.

To maximize the benefits and minimize the challenges of using these technologies, it is important for app developers, users, and regulatory authorities to work together to ensure the accuracy and reliability of the information provided by the app, the compliance with legal and regulatory requirements, and the cost-effectiveness of the technology.

Overall, the use of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes represents a promising and exciting development that has the potential to transform the way we inspect and maintain underground pipes. As the technology continues to evolve and improve, it is important for all stakeholders to stay informed and engaged in its development and use, and to work together to ensure that the benefits of the technology are realized, and the challenges are addressed.

Looking ahead, the potential uses and applications of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes are likely to expand and diversify, as the technology becomes more widely available and accessible, and as new needs and opportunities arise. For example, the technology may be used in a variety of sectors beyond utilities, such as transportation, agriculture, construction, and tourism, and it may be applied to a range of tasks beyond inspection and maintenance, such as mapping, surveying, and asset management. A proposed mobile app could be like the Fig.7

Fig.8 a proposed app view.

In this context, it is important for researchers, policymakers, and industry leaders to collaborate and innovate, and to identify and pursue new opportunities for the development and deployment of compass, GPS, gyroscope, and AR technology in smartphones for virtually seeing underground pipes. The potential benefits of such collaboration and innovation are significant, and they have the potential to create value and impact for a wide range of stakeholders, including consumers, businesses, and society.

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