

Tunnel Construction Site Monitoring and Digital Twin System

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Abstract— The digital twin is a new and important technology for digital transformation and intelligent updating. Using data and models, digital twins are capable of doing monitoring, modelling, prediction, optimization, and other activities. Digital twin modelling, in particular, is the key to correctly characterizing actual things, enabling digital twins to provide functional services, and meeting application requirements. In this work, a platform for supervising the building of tunnels using digital twins is suggested. Traditional tunnel construction management calls for skilled managers to conduct on-site inspections and recording, which takes time away from other crucial jobs and makes it easy for errors to occur due to the intricacy of the engineering. The digital twin visualization platform for tunnel construction can perform accurate real-time inspection, monitoring, and management of the construction process as well as complete overall management of the entire construction process when used in conjunction with other technologies like the Internet of Things, GNSS technology, 3D modeling, and others. It is a mix of engineering construction and contemporary digitalization that significantly reduces the amount of work and time required by obviating the requirement for skilled individuals to enter the site.

Keywords— Digital Twin, Tunnel Construction, Visualization, 3D Model, Management Platform

I. INTRODUCTION

The world is currently through a period of upheaval and heading toward the age of digital intelligence. Similar plans have been developed by every country in the world to get ready for the arrival of the digital era. When seen in this way, the idea of a "digital twin" appears at a critical juncture in human history, grows swiftly in recent years, and is now a fairly well-established concept in a number of industries, including intelligent manufacturing, health, urban planning, and others. Because it can provide real-time monitoring, efficient decision-making, in-depth analysis, augmentation, and optimization, the digital twin has a promising future. Since it was initially presented in 2003, the concept of a digital twin has expanded significantly over the previous 20 years. Digital twin technology has gotten good ratings from several organizations and academic institutions due to its unique advantages. The GNSS, 3D modelling, ultra-wideband

positioning, and other technologies are combined in the tunnel digital twin technology. The technology required to construct a digital twin has been constantly increasing as a result of recent scientific and technological advancements, which has allowed for the development and use of tunnel digital twin technology. The adoption of digital twin technology in the construction sector might be significantly boosted by its usage in tunnels.

II. TUNNEL DIGITAL TWIN TECHNOLOGY

A digital twin is a virtual representation or duplicate of a physical object. To actualize the prediction, detection, diagnosis, and optimization of a physical object's whole life cycle, combine foundational ideas like networks and perception with essential contemporary technologies like modeling and simulation. This system uses sensors for data collection, manual modeling with modeling tools, and Python code to update the data on the model in real-time in order to fulfill the aim of digital twinning.

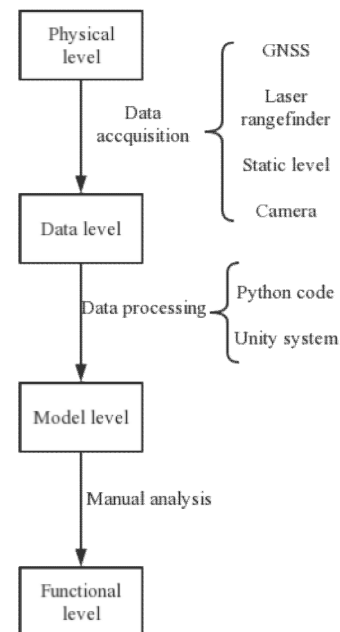


Figure 1. Technical architecture diagram

III. THE ESTABLISHMENT OF THE TUNNEL DIGITAL TWIN

A. Data Acquisition

The first step is data acquisition, which is accomplished by investing in sensors and detecting tools. The data upload channel and the command delivery channel are the two channels used for data transport. Before putting sensors and equipment on site based on the data collected, it is important to carefully consider the project's geographic surroundings, technical requirements, weather patterns, and other factors. The three primary types of data that are gathered are details regarding the condition of the labor, tunnel specifications, and the location of people and equipment.

Location information on persons and equipment is typically collected via UWB ultra-wideband positioning technology. The UWB positioning signal exceeds preceding technologies in terms of location accuracy with a frequency range of 3.1 to 10.6 GHz, a maximum coverage range of 100 m, and a maximum transmission speed of 460 Mbps. Finding employees involves using the positioning bracelet, which has a positioning chip. The device can be fitted with a positioning chip to enable exact installation. The positioning label is attached to the personnel and equipment, and the base station is deployed everywhere. Calculating the distance between each base station and the label involves comparing the timing of radio signals sent by the label and those from the various base stations.

This 3-dimensional UWB locating system uses eight base stations that are installed in the tunnel and are identified by the letters A1, A2, A3, A4, A5, A6, A7, and A8. The location information is altered to arrive at the most exact position based on the separation between the real label and each base station. In a reverse calculation, a point is initially assumed, then the distance between the point and base station is compared, and finally the distance between the label and base station. This procedure is carried out over and over again until the most precise position is found.

The X, Y, and Z axes are located between points A0 and A4, A0 and A1, and A0 and A3, respectively. A0 is the fixed base station for the tunnel's coordinate zero, or (0, 0, 0); the distance between A0 and A4 is fixed. This is depicted in Figure 2. The specifics of the staff deployment, monitoring, and layout plans determine where the label T0 will be placed, which is stated to be in the area between (x, y, z). The distance is also modified by the data file. The data that has been enhanced and rectified is calculated, acquired, and used by the system.

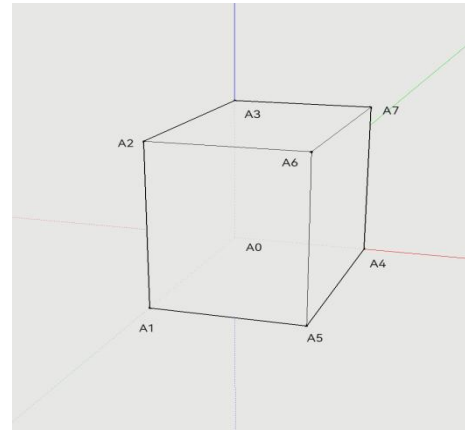


Figure 2. Base station layout

The listener gathers the measured data, which is subsequently transmitted to the system in the PC. The system incorporates the Python code to compute locations.

```
# The measured distance from the label to the eight base station
dist_data = []
for item in stations:
    t_dist = distance(tag_pos, item)
    dist_data.append(t_dist + random.random() * 0.3 - 0.15)

print("The distance between the tag and each base station: ")
print(dist_data)
```

Figure 3. Distance calculation code for the tag to the base station

```
def dist_diff(in_pos, t_dist_data, t_stations):
    """
    Calculate the distance between the existing
    guess coordinates and the base station,
    and calculate the average of the square of
    the difference from the actual measured distance.
    :param in_pos: Guess the coordinates of the points
    :param t_dist_data: Label to base station segment
    :param t_stations: base station coordinates
    :return:
    """
    sum = 0.0
    for i in range(len(t_stations)):
        t_d = distance(in_pos, t_stations[i])
        sum += (t_dist_data[i] - t_d) * (t_dist_data[i] - t_d)
    return sum / len(t_stations)

def my_dist(in_p):
    """
    Optimize the objective function, the smaller the return result,
    the closer the guessed coordinates are to the actual coordinates.
    :param in_p: Guess the coordinates of the points
    :return: The mean of the square of the difference between
    the guessed distance and the measured distance.
    """
    t_pos = {"x": in_p[0], "y": in_p[1], "z": in_p[2]}
    return dist_diff(t_pos, dist_data, stations)

print("guess the starting position of the tag: ", rand_point)
print("The squared mean of the distance to each base station: ",
      dist_diff(rand_point, dist_data, stations))

# Construct optimized initial guess coordinates
my_pos = [rand_point["x"], rand_point["y"], rand_point["z"]]
# Minimize a function using the downhill simplex algorithm.
# This algorithm only uses function values, not derivatives or second
# derivatives.
# Downhill simplex algorithm
res = fmin(my_dist, my_pos)
print("The optimization result is: ", res)

print("Label real coordinates: ", tag_pos)
print("The means of the distance squared: ", dist_diff(tag_pos, dist_data, stations))
```

Figure 4. Coordinate optimization code

To obtain tunnel parameters, the three basic methods are GNSS, static level, and laser rangefinder. The GNSS is a global satellite navigation system, and the absolute coordinates of the target can be obtained through the GNSS monitoring equipment. A 485 bus is used to connect each instrument and piece of gear in series, including the static level and laser rangefinder. When there is no network, radio communication modules are added while data transmission uses 4G/5G and other communication protocols. The PC or acquisition tool is linked to the DTU hardware, and signals are sent across the tunnel using the bridge. The DTU bridge is currently used to send the data gathered in the database or by the collection tool to the Internet network. DTU (Data Transfer unit) is a wireless terminal device specifically used for converting serial port data into IP data or for converting IP data into serial port data for transmission through a wireless communication network. The user may connect into the website and view the information that was measured about them. The user may then use the Python code on the computer to compute and store the data.

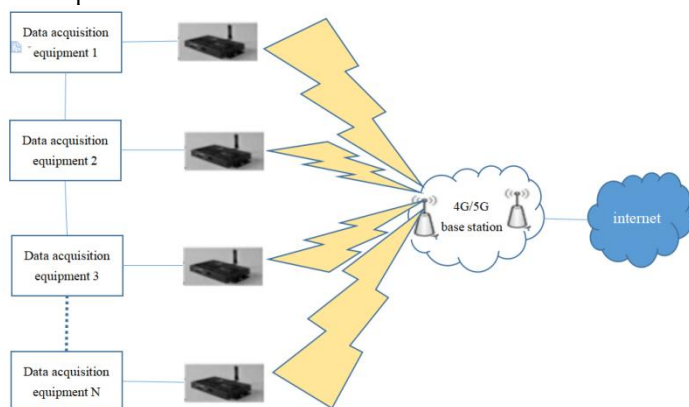


Figure 5. Schematic diagram of the data transmission

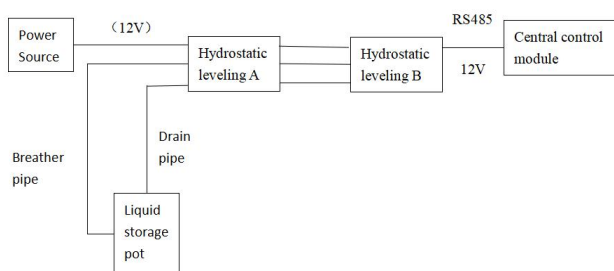


Figure 6. Schematic diagram of the static leveling system

This device is primarily used to collect information about employees' health status. The code is built to read the data from the APP and load it into the system when the bracelet and computer are linked via the APP.

The data are mostly generated throughout the process and include duration data. Data must be retained once it has been gathered. The system is equipped with a database that is set up to preserve data that can be saved as TXT text. The TXT format is a text document, and the TXT is an extension.



Figure 7. Positioning bracelet

```
# store laser data
laser = config['laser']
data_dict = {}
for i in laser:
    for k in i['sensor_num']:
        data_dict[(i['dtu_id'], str(k))] = None
self.laser = data_dict
# print("laser data",self.laser)

# laser acquisition command
laser_order = config['laser_order']
for i in laser_order:
    self.laser_order[i] = laser_order[i]
# print(self.laser_order)

# store static leveling data
hydrostatic_level = config['hydrostatic_level']
data_dict = {}
for i in hydrostatic_level:
    for k in i['sensor_num']:
        data_dict[(i['dtu_id'], str(k))] = None
self.hydrostatic_level = data_dict
# print("static leveling",self.hydrostatic_level)

# static leveling data acquisition instruction
hydrostatic_level_order = config['hydrostatic_level_order']
for i in hydrostatic_level_order:
    self.hydrostatic_level_order[i] = hydrostatic_level_order[i]
# print(hydrostatic_level_order)
```

Figure 8. Part of the Python code

B. Data Visualization

After the data collection is completed, the data must be processed when it is gathered so that it changes from an illusory number to a visible model, making the following steps easier.

The constructed model typically contains the topography and geomorphology, the interior construction of the tunnel, connected equipment, etc. 3D modeling software can finish the model creation process. Modeling software for the Unity 3D software, manual modeling to create the tunnel and mountain models, use of the Terri function in Unity 3D for

editing the relief of the terrain, trend, height, and texture, and modeling of the tunnel using geometric graphics.

The Unity platform is used to implement data visualization. Unity, a platform for game design, can implement multilingual and cross-platform design. The virtual entities are represented in Unity, which is made possible by Unity Shader.

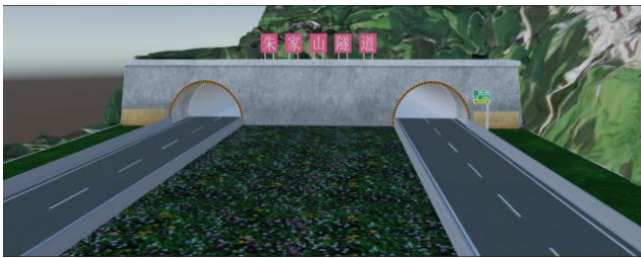


Figure 9. Three-dimensional model

C. Real-time Mapping of Data

The transmitted data must be overlaid on the model in real time for the digital twin to be able to accomplish real-time reflection of the physical model. The DTU implements data transmission, while the TCP protocol executes data transfer. The transmission signal can be guaranteed via the TCP protocol. TCP (Transmission Control Protocol) is a connection-oriented, reliable and byte stream-based transmission layer communication protocol.

The UGUI framework in the Unity system allows for the updating of the model, and the XChart open source chart plug-in in the Unity system enables users to alter and modify the internal software. In order to use XChart in Shader, you must first establish the canvas, then insert the appropriate chart, then editing the code that controls how the graph is updated. Under the UGUI architecture, Unity Shader analyzes the data and creates the real-time update of the model in conjunction with visualization tools.

D. Feedback and Adjustment

Digital twin is a dynamic process where data is continually transmitted from the physical model to the digital model, then changed in accordance with the digital model, and ultimately the optimization and improvement are sent back to the physical model to form a closure. The digital twin must be improved repeatedly to achieve the best application effect. Technical staff must perform in-depth analyses of the digital model in accordance with the data gathered by the monitoring equipment, then propose improvement measures, adjust the model, observe the situation of the improved model, and finally apply the adjustment to the actual project.

IV. TUNNEL CONSTRUCTION MANAGEMENT PLATFORM

The following features are primarily included in the digital twin management platform for tunnel construction: 3D roaming, construction progress management, real-time construction interface, and import and export monitoring. The platform's first interface, as shown in Figure 10, contains a brief summary of the building project, real-time time and weather information, and GNSS position information. At the bottom are the entrances to each functional region and the number of days that have been securely built.

A. 3D Roaming

The ability to browse the whole model, including the position of the tunnel, the depth of the tunnel, and the state of the mountains, is made possible by 3D roaming. A verbal description of the whole tunnel will be available while visitors are exploring the model to aid in their understanding of the process of construction.

B. Construction Progress

The ability to monitor project development in real time allows management staff to better understand the overall scope of the project. As shown in Figure 11, the finished paragraph and distance information of the current construction are represented by the colored paragraph.

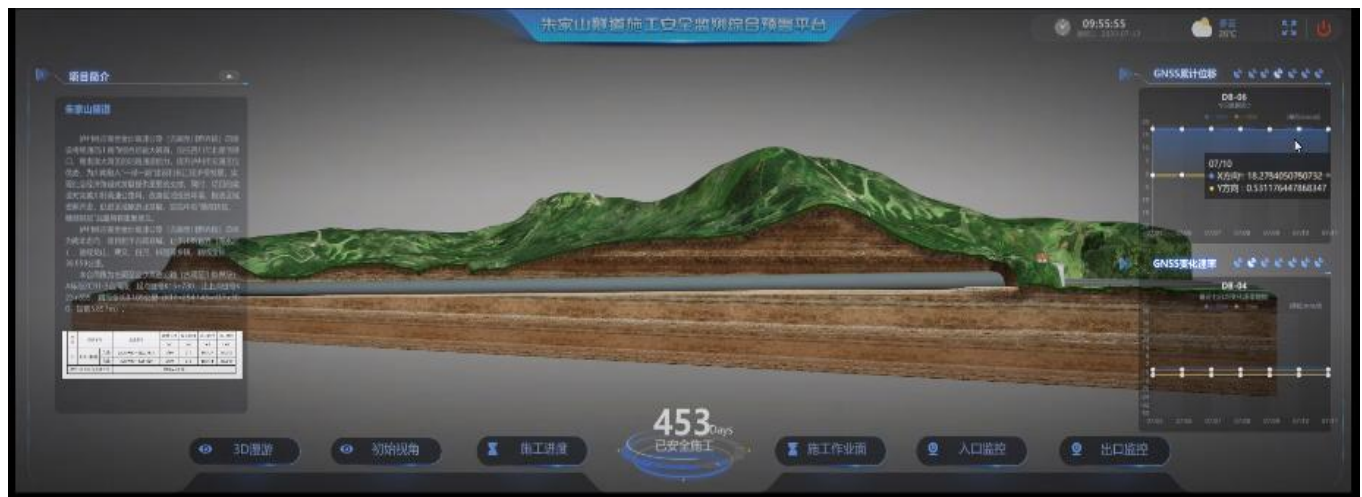


Figure 10. Initial interface diagram of the tunnel construction management platform

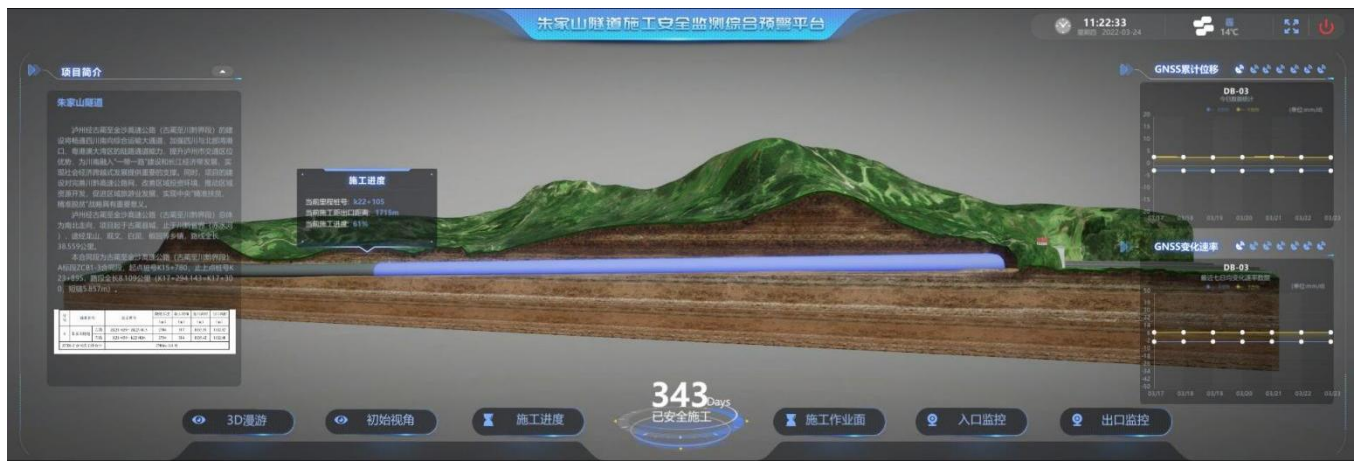


Figure 11. Construction progress

C. Construction Interface

The real-time construction situation, including the status of construction workers and equipment, may be tracked using the construction operation interface. It can also track the activity trajectory of workers and equipment. The real-time construction status is one of two key components of the construction operation interface. The other component is the duration playback. The real-time operating interface, shown in Figure 12, comprises data on the position of personnel equipment, static level data, laser rangefinder data, and personnel equipment health status. The kind of observation, the playback time, and the observation object may all be customized using a synchronized record.

D. Monitoring Interface

The entry and exit monitoring is positioned above the tunnel entrance and exit, allowing for real-time monitoring of the status of both. When utilizing, just click the monitoring symbol on the model, and the monitoring screen will display in the interface's center.

V. CONCLUSION

Digital twin is a relatively new technology, which has a relatively complete theory has been applied in many fields. Tunnel construction might benefit from the use of digital twins. Data collection, transmission, processing, visualization, and modeling are the key methods used to construct the tunnel digital twin system, and each of these processes is interconnected. By enabling real-time tunnel simulation and tracking throughout the whole life cycle, the tunnel digital twin system allows management staff can monitor and control the entire tunnel construction process remotely from their computers, significantly reducing the need for labor and material resources. Due to its advantages in ease, speed, and accuracy, tunnel digital twin as a novel technology offers enormous development potential. Future development of the digital twin system for tunnels is expected to be significant. This paper can make some contribution and reference to the application of digital twin in the field of architecture.

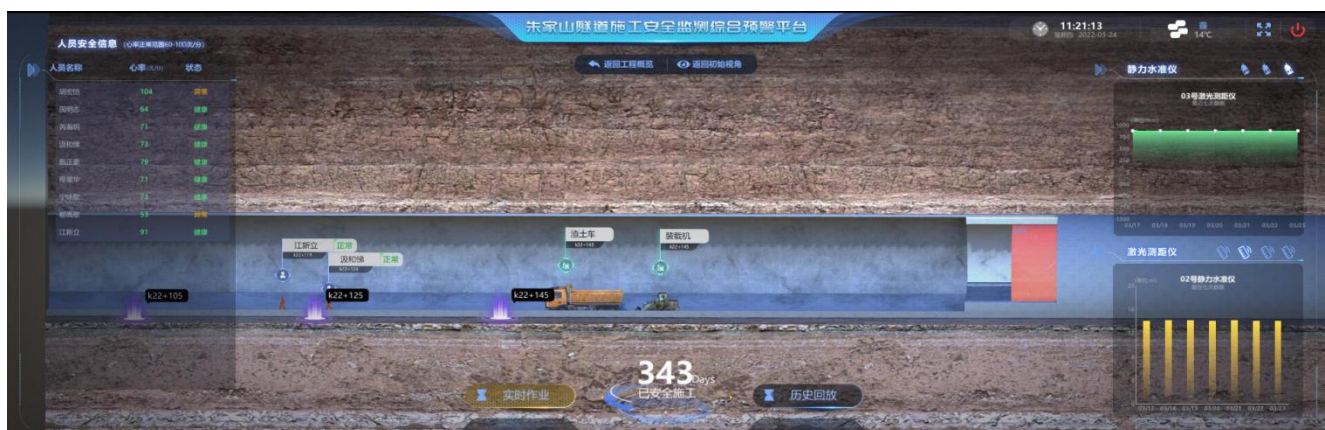


Figure 12. Real-time construction

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