TOWER TILT MONITORING
WITH WIRELESS TWO-WAY INTERFEROMETRY (WI-WI)

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ABSTRACT

We demonstrated a new method to monitor tilt of a 60 m steel tower with millimeter precision, based on Wireless two Way interferometry technique (Wi-Wi). The result is consistent with the results from a laser range finder. We then developed a compact module to realize Wi-Wi for non-destructive infrastructure monitoring. We expect this technique to be useful to assess infrastructural health and provide early warning in case of the need for repair, replacement.

KEYWORDS: Synchronization, Nondestructive testing, Wireless communication, Interferometry.

1. INTRODUCTION

Destruction due to aged infrastructure causes major disasters, especially in big cities in developed countries. Thus, it is important to inspect the condition and behavior of aged buildings to plan maintenance protocols based on scientific data. In particular, during the high economic growth period after the Second World War, many concrete buildings were built in a short time. Lifetime prediction technology for such infrastructure is desired worldwide. In Japan, huge earthquakes sometimes occur, so there are very strict standards for the seismic performance of new buildings. For the measurement of the local and instantaneous behaviors of buildings due to external vibrations, the development of deterioration diagnosis technology is progressing. For example, previous works suggested that the frequency analysis of monitoring data obtained by using strain sensors and accelerometers can give useful information on ageing. [1, 2]

On the other hand, measurement of the displacement of a building relative to the slow movement of the ground, such as land subsidence, requires periodic measurements by a skilled person using a manual tool such as a laser range finder (a total station, etc.). Although the accuracy of distance measurement by a total station is extremely high, it requires manual work by a skilled person, so that the cost rises when the number of measurements increases. On the other hand, position monitoring by using GPS modules has been used in a wide range of fields, such as agriculture. For example, the number of drones used for crop-spraying that are controlled by a GPS system is increasing rapidly. However, the spatial resolution is not as high as mm order, making it difficult to apply GPS modules for building diagnosis.

We have developed a technique that enables real-time and high-precision displacement measurement using common microwave modules and have performed feasibility studies on its application to civil engineering. In addition to monitoring existing buildings, we also work with construction companies to monitor the displacement of land during construction. Since the technique uses a common telecommunication module, the whole system is inexpensive, and data can be easily transferred through existing networks. In this report, as a preliminary demonstration experiment in the field, we introduce the result of monitoring the displacement of a 60 m tower in the NICT campus.

2. WIRELESS TWO-WAY INTERFEROMETRY (WI-WI) TECHNIQUE

NICT is a national institute responsible for the distribution of Japan Standard Time, which is becoming increasingly important with the increase in instantaneous network trading and banking businesses. In order to ensure the accuracy of domestic standard time and to generate international standard time, the time is compared among countries by using satellite telecommunication. For example, when Japan Standard Time is sent to Germany via a communication satellite, it will be delayed by the propagation time when it is received in Germany, and vice versa. Comparing the time differences that includes propagation time, measured at both ends, one can calculate both propagation time and time difference. This technique is widely known as a two-way satellite time and frequency transfer (TWSTFT) technique [3], and the propagation distance of radio waves can be obtained simultaneously with the time difference. As described in Fig. 1, we have expanded this technology and developed the wireless two-way interferometry (Wi-Wi) technique using
a common telecommunication module [4, 5]. First of all, as a proof of principle, we accurately changed the distance between two antennas using a stepping motor. When we performed measurements using a 2.4 GHz Zigbee module, laboratory-level Wi-Wi technology using software-defined radio (SDR) with two receivers, and a rubidium clock, a displacement of 1 mm was obtained, as shown in Fig. 2.

On the basis of this result, we developed the compact and inexpensive Wi-Wi module shown in Fig. 3 using a high-precision crystal and a 920 MHz telecommunication chip. By placing at least three units and measuring the distances between each pair of modules, three-dimensional positioning is possible.

![Fig. 1 Principle of Wi-Wi technique, (a) two-way satellite time and frequency transfer (TWSTFT), (b) wireless two-way interferometry (Wi-Wi).](image)

![Fig. 2 Demonstration of displacement measurement by Wi-Wi technique.](image)

![Fig. 3 Wi-Wi module and setup for three-dimensional displacement-measurement system.](image)
3. MONITORING RESULTS OF TOWER DISPLACEMENT

Prior to the demonstration experiment in the field, the displacement of the 60 m tower in the NICT campus was measured. As shown in Fig. 4, the distance between two points, one on the tower and one on Building No. 6, was measured by the Wi-Wi technique and with a laser range finder for comparison. The tower is to the south of Building 6, and the relative position of the sun is shown in the inset. We placed a total station on Building No. 6 and a reflection prism on the steel tower. The distance between them was roughly 124 m, and the variation of the distance was monitored precisely for 9 days by the Wi-Wi technique as well as with the total station.

Fig. 5 shows the change in distance measured by the total station as a red line and that measured by the Wi-Wi technique as a blue line. The result shows that the distance is decreased by nearly 20 mm around noon each day and returns to its original value each night. In essence, we measured the tilt of the tower due to the uneven heating by sunlight. As the sun rises in the eastern sky and approaches its zenith, the sun’s uneven heating causes the tower to expand on the south side, resulting in a tilt toward the north. The relatively small displacement on 6th March may have been due to cloudy weather.
Subsequently, as shown in Fig. 6, the Wi-Wi module was installed at three other locations and the three-dimensional displacement of the steel tower was observed for 4 days. Here, when the distance was measured with radio waves, it was necessary to consider the influence of changes in atmospheric conditions on the propagation characteristics of the microwave. Thus, changes in the refractive index of the atmosphere were calculated from temperature, humidity, and pressure data in this observation area (Fig. 7) in order to determine the influence. Although the displacement data described below were corrected accordingly, the influence on the displacement measurement was less than 0.001%.

Fig. 6. Setup for displacement monitoring of the 60 m tower.

Fig. 7. Changes in temperature, pressure, humidity with the time of day and its influence on refractive index on 3 August.
Fig. 8 shows the changes in the distance between each building and the steel tower over 4 days (3rd-6th August). The maximum variation appeared at around noon, and the variation can reach 25 mm. Some sharp peaks appeared in the night of 3 August. It can be due to either an unexpected interruption including a bird, or movement of modules that were installed in an unstable condition.

Using these data, the position of the steel tower over time was calculated by geometric calculation and was plotted on the XY plane, i.e., parallel to the ground, where the X- and Y-axes indicate east-west and north-south, respectively. Fig. 9 shows an example of the displacement during the daytime on 3rd August, which was a sunny day. The tower started to move along the east-west axis at sunrise, then gradually along the north-south axis. The greatest north-south variation was recorded around 13:00, and the tower returned to the original position at sunset. The movement might have been due to the expansion of iron induced by the temperature rise caused by sunshine.

Fig. 8. Displacement monitoring between the 60 m tower and three buildings from 3rd to 6th August.

Fig. 9. Movement of the 60 m tower. The number with the plot indicates the time on 3rd August.
3. CONCLUSION

We have developed a technique that enables real-time and high-precision displacement measurement using common microwave modules called wireless two-way interferometry (Wi-Wi). A feasibility study on its application to the monitoring of buildings suggests that the mm-order movement of buildings can be monitored. Although this technique may not be directly categorized in nondestructive testing techniques, Wi-Wi modules can be added in various nondestructive observation systems for their synchronization.

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REFERENCES