Research on multi-source data integration and the extraction of three-dimensional displacement field based on GBSAR

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ABSTRACT

Only the displacement along the radar line of sight can be got in Ground Based Synthetic Aperture Radar (GBSAR). In order to extract high-precision three-dimensional displacement field of research area, in this article, we research deeply the method which integrates both three-dimensional laser scanning and GBSAR techniques. It is proved that high precision three-dimensional displacement field information can be extracted with this method through analyzing case and assessing the accuracy of three-dimensional displacement field. The method has a good practical value.

Keywords: GBSAR, three-dimensional laser scanner, deformation monitoring, high precision, high spatial resolution, high sampling frequency, microwave detecting, three-dimensional displacement field

1. INTRODUCTION

Deformation monitoring is a technique which is defining the deformable bodies’ spatial position and internal morphological variation with time by periodic monitoring \cite{1}. The traditional means of monitoring have low spatial resolution, poor continuity and influenced by the environment. These drawbacks hinder the application and development of deformation monitoring. How to quickly get the high precision, high spatial resolution three-dimensional displacement field deformation monitoring information of the deformable bodies has become a research focus. In recent years, Synthetic Aperture Radar (SAR) deformation monitoring technique has opened up a new path \cite{2}. With the continuous development and improvement of SAR, it has been successfully used in geology, hydrology, mapping, military, environmental monitoring and so on \cite{3}.

Three-dimensional laser scanning is a new mapping technique which can quickly obtain the raw survey data and accurately reconstruct the three-dimensional model of scanning entity \cite{4,5}. The technique which has the advantage including high precision, high speed, wide range of applications, overcomes the disadvantages of traditional single-point measurement methods. It is one of the hot research fields. It has been widely used in deformation monitoring of buildings. As a new variant of the terrain monitoring equipment, GBSAR has its advantages such as high speed, high precision, wide coverage, portability, easy to operate, etc. Though GBSAR is a potential new space geodetic method, it

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has its inherent limitations \[7-8\]. The data quality is affected by atmospheric effects, the stability of observation platform and system noise. In addition, GBSAR technique can only get the displacement of the deformable bodies on the radar sight line. It cannot directly extract the three-dimensional displacement field of the deformable bodies that limits the applications of GBSAR \[9-11\]. The three-dimensional laser can obtain three-dimensional information deformable body. However, it is limited by the scope of its observation. If the integration of these two techniques complement each other, we can get high-precision three-dimensional displacement field. The integration of GBSAR and three-dimensional laser scanning enables rapidly access to high-precision three-dimensional displacement field. But the research on fusion technique is still not deep enough. Therefore, there will be good theoretical and practical value to carry out the research on the integration of three-dimensional laser scanning and GBSAR, and propose a set of practical technical solutions \[12\].

2. THE PRINCIPLE OF EXTRACTING THREE-DIMENSIONAL DISPLACEMENT FIELD BY INTEGRATING THREE-DIMENSIONAL LASER SCANNING AND GBSAR

Though the accuracy of deformation monitoring GBSAR obtained is sub-millimeter level, the deformation is on the radar sight line, and not a true reflection of the three-dimensional object deformation monitoring information. Three-dimensional laser can obtain three-dimensional coordinates of the deformable bodies by scanning quickly. By effective integrating the high spatial resolution three-dimensional laser scanning point cloud data and high-precision deformation monitoring information obtained by GBSAR, we can achieve a three-dimensional displacement field of deformable bodies. The principle is shown in Figure 1.

![Figure 1](image-url)

Figure 1. The geometric diagram by integrating three-dimensional laser scanning point cloud data and GBSAR monitoring data.

In the figure 1, three-dimensional laser scanner and GBSAR device are located on $L(x_L, y_L, z_L)$ and $G(x_G, y_G, z_G)$ under the reference coordinates. In the figure 1, $\theta_L$ and $\theta_G$ represent the three-dimensional laser scanner and GBSAR instrument to the angle of incidence of the monitoring points $R(x, y, z)$. 

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\( \alpha_L \) and \( \alpha_G \) represent the angle between the projection of \( LP \) and \( GP \) on reference plane \( xoy \) and the axis \( x \). First, we should choose some stable same name points in the monitored area, set up corner reflectors on the points and measure their dimensional coordinates \( (x'_0, y'_0, z'_0), (i = 1, 2, \cdots, N) \). \( N \) represents the number of corner reflectors. We find the coordinates \( (x'_G, y'_G, z'_G) \) of the corresponding point of the corner reflector \( (x'_L, y'_L) \) in the point cloud data of three-dimensional laser scanning and GBSAR monitoring data.

\[
\begin{align*}
x'_0 &= G(x'_L, y'_L) = L(x'_G, y'_G, z'_G) \\
y'_0 &= G(x'_L, y'_L) = L(x'_G, y'_G, z'_G) \\
z'_0 &= G(x'_L, y'_L) = L(x'_G, y'_G, z'_G)
\end{align*}
\] (1)

\( G(x_G, y_G), (i = 1, 2, 3) \) is the conversion function that converts the pixel coordinates GBSAR \( (x_G, y_G) \) to the reference coordinates \( (x, y, z) \). \( L(x, y, z), (i = 1, 2, 3) \) is the conversion function that converts three-dimensional laser scanning data \( (x'_L, y'_L, z'_L) \) to reference coordinate \( (x, y, z) \). The converted function can be used polynomial function or other functions. After registration, three-dimensional laser scanning point cloud data and monitoring data of GBSAR were registered to unified reference coordinate system. By using coordinate inverse formula in Figure 1, we can get

\[
tan \alpha_G = \frac{y - y_G}{x - x_G}
\] (2)

According to the obtained \( \alpha_G, \theta_G \), it can be drawn

\[
\begin{bmatrix}
-\cos \alpha_G \cos \theta_G & \sin \alpha_G \cos \theta_G & \sin \theta_G
\end{bmatrix}
\begin{bmatrix}
\Delta x \\
\Delta y \\
\Delta z
\end{bmatrix}
= r_{def} = \frac{\Delta \phi}{4\pi \lambda}
\] (3)

Let

\[
B = \begin{bmatrix}
-\cos \alpha_G \cos \theta_G & \sin \alpha_G \cos \theta_G & \sin \theta_G
\end{bmatrix}
\] (4)

\[
\Delta = \begin{bmatrix}
\Delta x \\
\Delta y \\
\Delta z
\end{bmatrix}
\] (5)
Formula (3) can be turned into

\[ B\Delta = L \]  \hspace{1cm} (7)

Constructing error equation

\[ v = B \cdot \Delta - l \]  \hspace{1cm} (8)

It can be obtained by least squares principle

\[ B^T PB = B^T \Phi \]  \hspace{1cm} (9)

Then

\[ B^T PB = \begin{pmatrix}
\cos^2 \alpha_G \cos^2 \theta_G & - \sin \alpha_G \cos \alpha_G \cos^2 \theta_G & - \cos \alpha_G \sin \theta_G \cos \theta_G \\
- \sin \alpha_G \cos \alpha_G \cos^2 \theta_G & \sin^2 \alpha_G \cos^2 \theta_G & \sin \alpha_G \sin \theta_G \cos \theta_G \\
- \sin \theta_G \cos \alpha_G \cos \theta_G & \sin \alpha_G \cos \alpha_G \sin \theta_G & \sin \theta_G \sin \theta_G \cos \theta_G \\
\end{pmatrix} \]  \hspace{1cm} (10)

Because of \( \det |B^T PB| = 0 \), formula (10) has no unique solution. In order to determine a unique solution, adding the minimum norm condition

\[ \Delta^T \Delta = \min \]  \hspace{1cm} (11)

Eventually we can get three-dimensional displacement field of monitoring area as followed formula

\[ \Delta = B^T \Phi (B^T PB B^T) B^T \Phi \]  \hspace{1cm} (12)

3. EXPERIMENTAL ANALYSIS

According to the principle of the integration of technique, the experiment continuous observed a large building by using three-dimensional laser and GBSAR at the same time. By registering, interfering, unwrapping and other treatment, we ultimately get the displacement on the radar sight line. The results were showed in figure 2.

![Figure 2. Line of sight to the displacement.](http://proceedings.spiedigitallibrary.org/ss/Download.aspx?doi=10.1117/12.2203499)
As it can be seen from figure 2, the displacement of deformation monitoring objects is between -2.5 ~ 2.5 mm. However, the displacement is on the radar sight line. According to the method mentioned before, we can extract three-dimensional displacement field in the region after registering the three-dimensional laser scanning point cloud data and GBSAR monitoring data. The results were shown in Figure 3 to 5.

![Figure 3. X-direction displacement.](image)

![Figure 4. Y-direction displacement.](image)

![Figure 5. Z-direction displacement.](image)

To check the accuracy of three dimensional displacement field, we can get its covariance matrix by following formula (13).

\[
D = \sigma^2 Q = \sigma^2 B^T P E (B^T P B B^T P B)^{-1} B^T P E (B^T P B B^T P B)^{-1} B^T P B
\]

(13)

Where: $\sigma^2$ is the unit weight variance, $Q$ is the covariance.

The precision of three-dimensional displacement field was shown in figure 6.
Figure 6. Three-dimensional displacement field precision Figure.
From the figure 6, we can know that the precision of three-dimensional displacement field is within 0.1mm. It illustrates that the precision of three-dimensional displacement field by integrating three dimensional laser scanning point cloud data and GBASR is high.

4. CONCLUSION

Because GBSAR can only get the displacement of the deformable bodies on the radar sight line, the article proposed the extracting three dimensional displacement field method that integrates three dimensional laser scanning point cloud data and GBSAR. Combined with case studies, it verified the feasibility and accuracy of the method, which provides a new approach for the application of GBSAR in deformation monitoring. Meanwhile, based on the three-dimensional displacement field of deformable bodies, we can predict the deformation tendency and ensure deformable bodies’ safety, combining with the deformable bodies’ mechanism and the appropriate forecasting model.

REFERENCES


