

# Monitoring Deformation of a Church's Tower by Laser Scanning

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## ABSTRACT

Churches are part of heritage structures that take an important role in Europe cultural identity. As such, these structures must be protected to prevent catastrophic collapse and any damage must be reported timely to establish planning to maintenance and restoration. This can be achievable when the churches are to be periodic monitoring with high frequency. However, this strategy has not been available in the most of the Europe's churches as a complexity of the church structures and limited budget. Laser scanning has been widely used in capturing rich (3D) three-dimensional topographic data of visible surfaces of the structure with high accuracy and low-cost in operation. This paper presents a methodology to monitor deformation of the church's tower using a terrestrial laser scanning. First, point clouds of the tower captured different views and period time are registered into the same coordinate system by using features of undeformed surrounding undeformed structures. An implementation of this task can not only eliminate requirements of fixed control points in data acquisition that are used for mapping the different data in a pre-processing step, but also track deformation of the tower over period time. Next, the paper proposed a multiple-level deformation measurement method (called global and local levels) to determine the deformation of the tower directly from the point cloud. In the global level, the skeleton approach is implemented to identify a centroid gravity of the tower's cross-section and a connection of these centroids represents to a neutral axis of the tower. A deviation of the centroid line from the reference line depicts a global deformation, which can also support to identify a direction of major deformation. Next, in the local level, the proposed method automatically extracts features of the structural components (e.g. a plane, edges of windows and the wall) from the point cloud. This can be obtained by empowering a voxelization model to efficiently extract the features of the structural components. Subsequently, fitting line and surface of the structures are compared to the reference objects to determine the deformation and also monitor deformation of the tower. The proposed method is implemented and used to monitoring of the towers of the Oude Kerk church in Delft and St. Brave Church in Haarlem, The Netherlands. Through the experimental test, this study also presents a lesson in data acquisition and point cloud processing for deformation monitoring, which can be used for similar heritage structures.