

Shape Measurement of Large Scale Components Employing Wireless Sensor Networks

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Summary: In this paper a wireless sensor network for measuring large scale components is presented. Accordingly, the methods of previous works for basic position calculations [1] and determining measurement uncertainties [2] are combined to implement a fully operational measurement system. Furthermore, a minimal-cost path is employed to optimize uncertainty in probe positioning calculations. Additionally, an approach for determining the structure shape via a least-square fit is demonstrated taking into account position uncertainty of each sensor probe. In order to demonstrate the feasibility a real-world measurement is presented.

Keywords: Sensor Network, Wireless, Shape Measurement, Large Structures Measurement, Least-Square-Fit

Motivation

Often it is not possible to measure the shape of a large object in real-time due to the large amount of time required. Therefore, we propose a wireless sensor network for determining the structure shape in real-time via distributed and interconnected sensors attached to the surface. Each probe measures the surface normal at its position and the distance to its directly neighboring probes. In recent works we demonstrated the construction of a sensor network capable of measuring the shape of an object in real time [1]. Additionally, we estimated the uncertainty of such a sensor network in accordance with the "GUM" [3], resulting in an application dependent quality indication for uncertainty [2]. Moreover, we investigated the uncertainty estimation through the utilization of a Monte Carlo method employing a least squares fit, as detailed in [4]. In this work we want to combine the previous methods to prove the working principle within a network consisting of 22 sensor probes and 48 connections. Furthermore, we want to show the needed calculations to determine the shape of an object. The component with the sensor network is shown in Fig. 1.

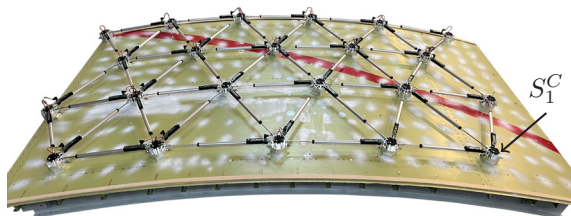


Fig. 1: Measurement object with the applied sensor network consisting of 22 sensor probes.

Shape Calculation

For the shape calculations each sensor probe position has to be evaluated in a reference probe coordinate system, which is used to translated into the component coordinate system. In our setup probe #1 (lower right in Fig. 1) is used as a reference probe denoted with the superscript "C". Due to the network structure each position can be calculated along several paths. However, it is more practical to use the path with the lowest position uncertainty. This can be achieved by determining the minimal cost path by using the A*-Algorithm from [5]. Since the network can also mathematically be described as an undirected graph. The network structure with its interconnections is shown in Fig. 2. As weights between the nodes the Euclidean distance uncertainty of the probes position is used by applying the estimations from [2]. The result is a tree with interconnections, where the path through the branches with the lowest position uncertainty in respect to the reference node coordinate system is determined.

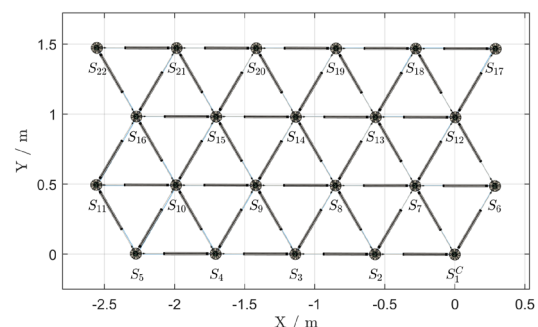


Fig. 2: Network structure of the applied sensor network from Fig. 1 with 22 nodes and 48 connections.

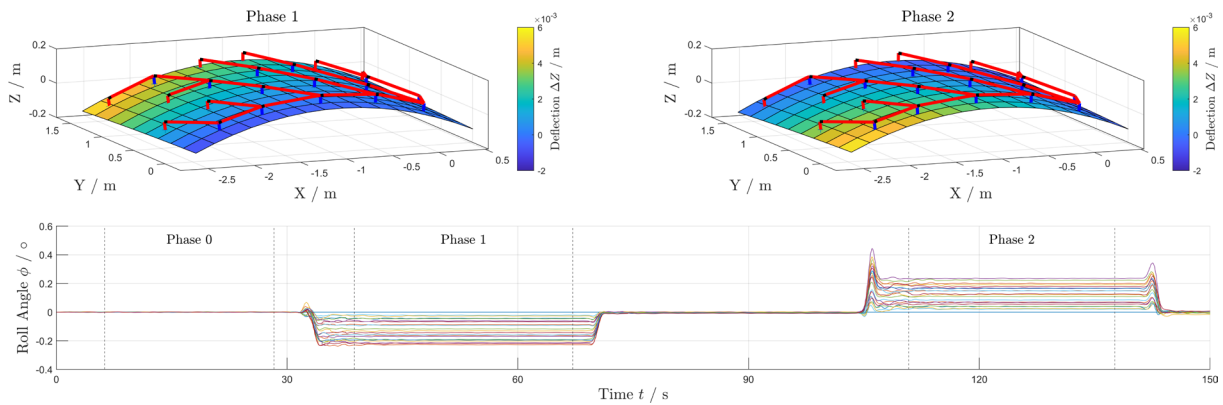


Fig. 3: Shape calculation of the component from Fig. 1 in phase 1 and phase 2, showing a deflection in Z direction to the phase 0. Results visualized as heat map with attached sensor network, minimal uncertainty path marked in red.

Subsequently, the surface shape can be reconstructed using a two-dimensional polynomial via a least-squares fit. The positions with the associated uncertainties are used for the fit calculation. For position estimation also the angles of the measuring probes can be used, as the angle information corresponds to the slope of the surface at the calculated probes position, respectively. This can be realized by extending the fit algorithm with the first derivative of the polynomial.

Measurement

Figure 3 shows the deformation resulting from lifting the component's edge ≈ 6 mm generating a torsional load on the component. The measurement is divided into three phases. Phase 0: initial shape, structure lies flat on the floor, phase 2: uplift of rear left corner and phase 2: uplift of front left corner. The two upper graphs show the calculated shapes of the component in phases 1 and 2 with the sensor networks minimal uncertainty path highlighted in red. The change in the Z direction with respect to the initial phase 0 is presented with the color map. Both phases show similar displacements. Also, the lifting point is visible on the heat map and shows that the component is lifted locally only on at a corner of the structure. The bottom graph shows the roll angle to illustrate the different stages in time. At the end of the measurement process the structure returns to its original shape.

Results

In this work we demonstrated that a real-time monitoring of large-scale structures with precise position and shape specifications is feasible, employing a wireless sensor network, which has been mounted on a test structure. Probe positions and the determination of the structure shape has been realized using a least-squares fit algorithm. In a future work the measurement results are cross-checked with a LASER-based reference measurement system.

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