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Cyber Physical Finite Element Sensor Network (CPFEN)

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Motivation

In modern manufacturing processes it is mandatory that the components to be manufactured are produced within well-defined tolerances. If only small production tolerances are permitted this often means that all production steps have to be monitored, which is a challenging task, e.g. in the production of large-scale components, where it is often not possible to determine the exact shape or surface stress in real-time during forming or deformation processes. Here, a standard solution is the use of laser trackers, typically requiring a human operator or a robot during the measurement process. Also, measurement time increases drastically with the size of the component. In this project we suggest an approach, where we measure the shape of an object with a finite grid of wireless sensor probes in real-time during the fabrication process. The sensor network measures the surface at discrete points in a similar way classical finite elements (FEM) discretize a volume for modeling the physical behavior. Hence, this measurement system is called a Cyber-Physical Finite-Element-Network (CPFEN).

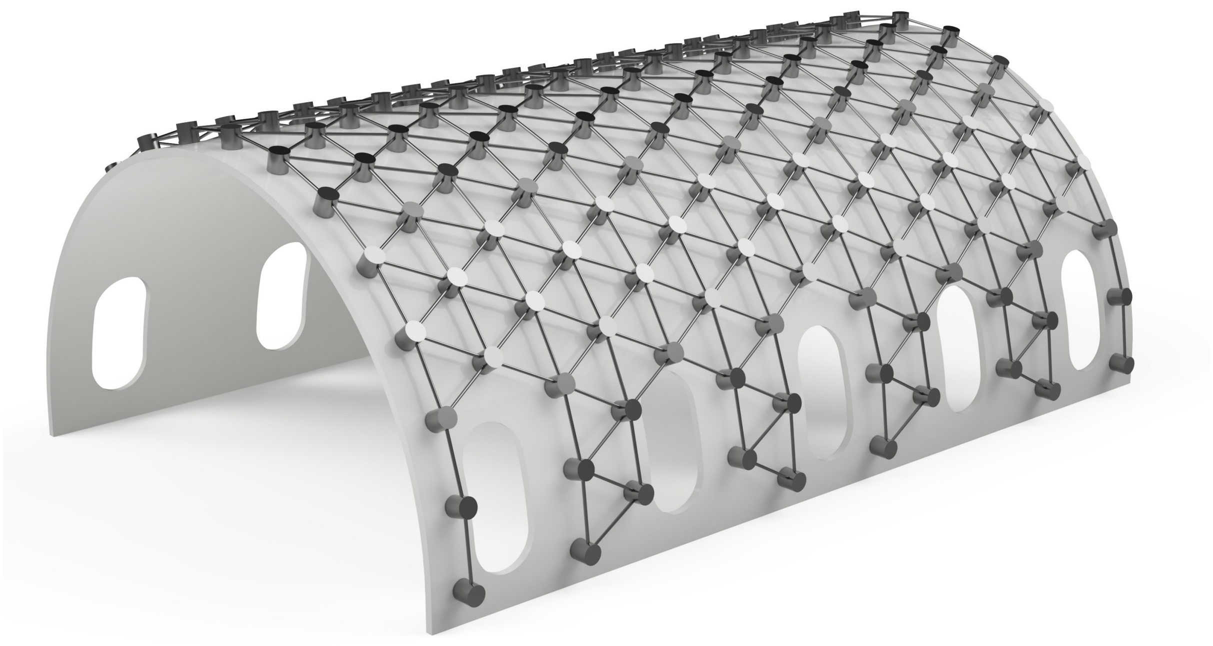

Fig. 1. Example application of the sensor network on an aircraft fuselage

Measurement System

The measurement system is supposed to be a physical implementation of a mechanical FEM, consisting of a mesh with nodes and connections between each node. An example implementation of a CPFEN is shown in Fig. 2. Each knot consists of a sensor probe and up to six rods connecting neighboring probes. The sensor probes are arranged in such a way, that three nodes form a triangle. This results in a clearly determined shape, which can be described with the cosine theorem.

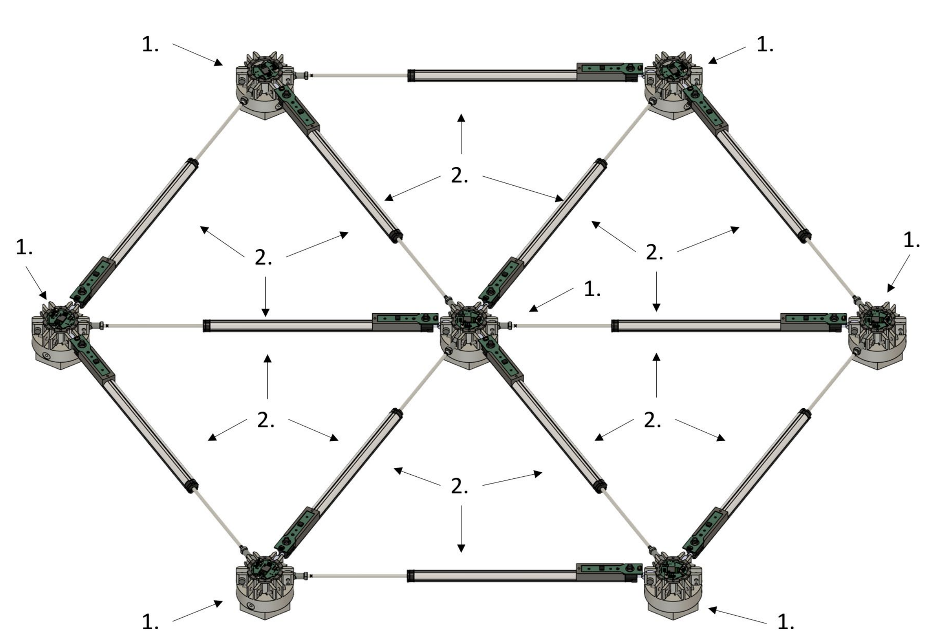

Fig. 2. Physical implementation of a FEM, 1. Sensor probe 2. Connecting rod.

From each sensor probe the relative distance to the neighboring probes can be determined with multiple integrated sensors. The position of all probes in the local coordinate system can be determined with the help of the measured angles and distances taking into account the geometric dependencies illustrated in Fig. 3. Therefore, the sensor network can measure surface deformations caused by tensile, compressional or bending forces. A central computing unit determines the position information of each sensor probe in the measurement objects coordinate system. This is done with one or more well-known reference probes. These reference probes have a precise position on the objects surface, which are mechanical or externally measured references [1].

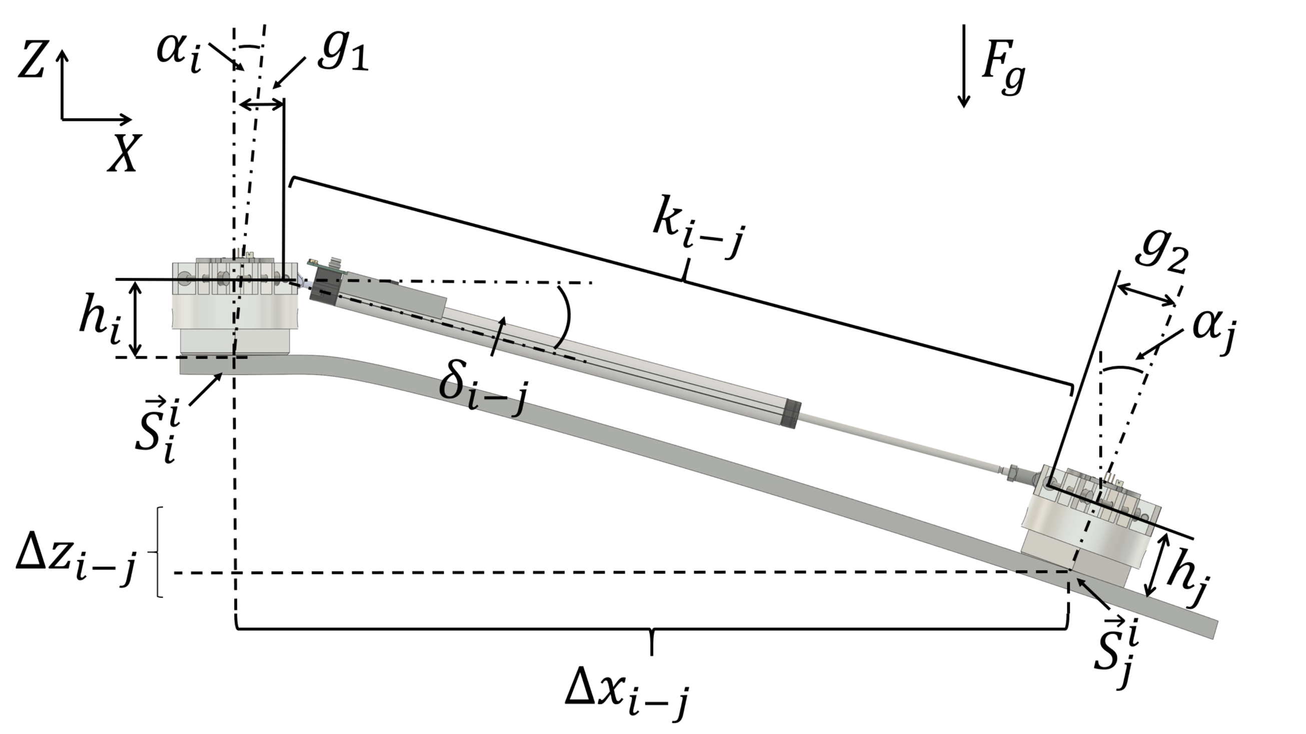

Fig. 3 Connection between two sensor probes with all necessary parameters and mechanical dimensions.

Measurement Uncertainty

Due to the complex calculations and the great number of sensors the position uncertainty of each sensor probe has to be evaluated according to the "Guide of Uncertainty Measurement" [3]. The uncertainty of the sensor probes position can be determined with the help of the sensor uncertainties and the mechanical uncertainties in a global and local coordinate system [2].

References

[1] L.-M. Bretthauer, R. Heynicke, and G. Scholl, "Proposal of a Cyber Physical Finite Element Sensor Network for Surface Measurements," in 2024 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), May 2024, pp. 1–6. doi:10.1109/I2MTC60896.2024.10560668.

[2] L.-M. Bretthauer, R. Heynicke, and G. Scholl, "D5.1 - Uncertainty Modeling of a Cyber-Physical Finite Element Sensor Network for Surface Measurements," vol. 22. GMA/ITG-Fachtagung Sensoren und Messsysteme 2024, pp. 380–387, Jun. 2024, doi:10.5162/sensoren2024/D5.1.

[3] BIPM et al., "Evaluation of measurement data — Guide to the expression of uncertainty in measurement." Joint Committee for Guides in Metrology, JCGM 100:2008, Sep. 2008. [Online]. Available: https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6

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