# Sensor Fusion for Shape Sensing
## Theory and Numerical Simulation

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# Sensor Fusion For Shape Sensing: Theory and Numerical Results

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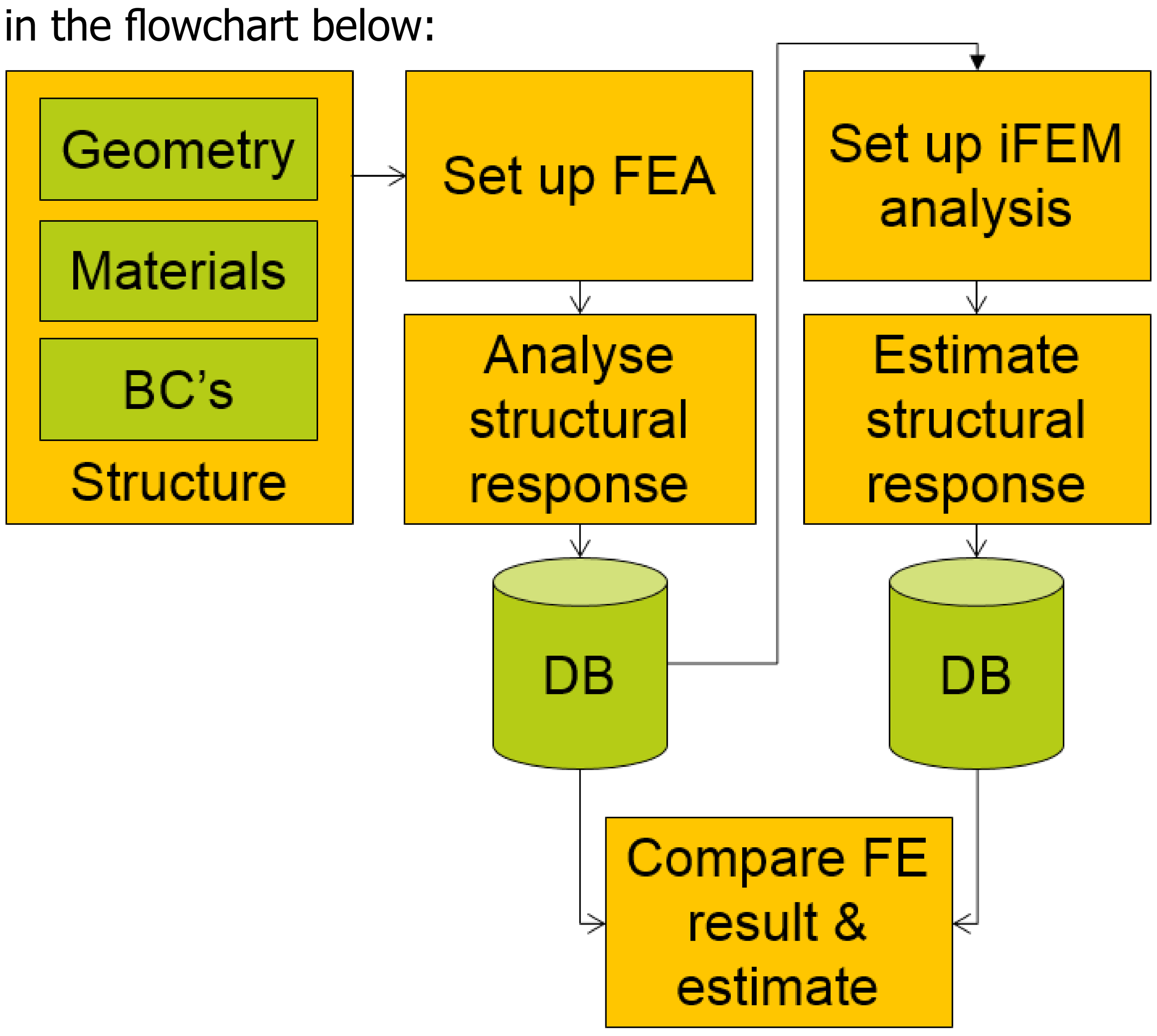
## Introduction

An inverse finite element (iFEM) algorithm was developed for shape sensing. The algorithm uses result smoothing through Tikhonov regularization while compensating for missing sensor data/measurements. In this study, a cantilever plate subjected to a point bending load is considered. The aim of this study is to accurately determine global strain distributions with as few sensors as possible.

## Method

The iFEM algorithm compares numerical strains and/or displacements to those obtained from sensors mounted on the structure or simulated based on FEA results. This is shown in the flowchart below:



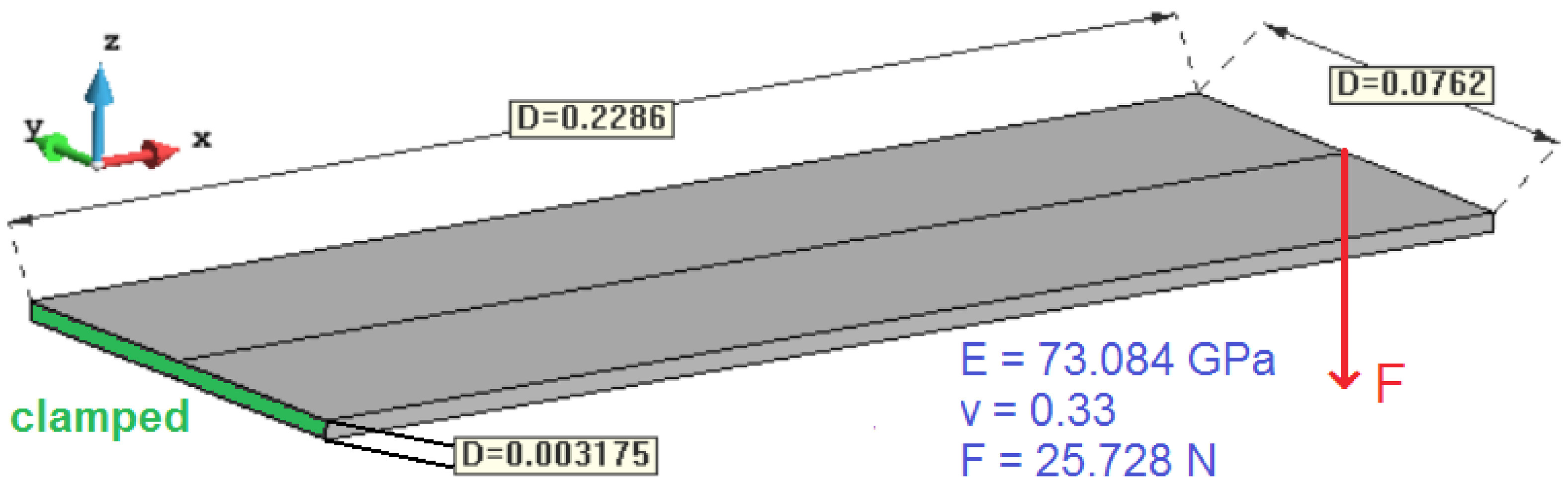

The iFEM error functional is based on the squared differences between the numerical and the measured values:

$$\boldsymbol{\Phi} = C_e\|\boldsymbol{e} - \boldsymbol{e}^{\varepsilon}\|^2 + C_d\|\boldsymbol{q} - \boldsymbol{q}^{\varepsilon}\|^2$$

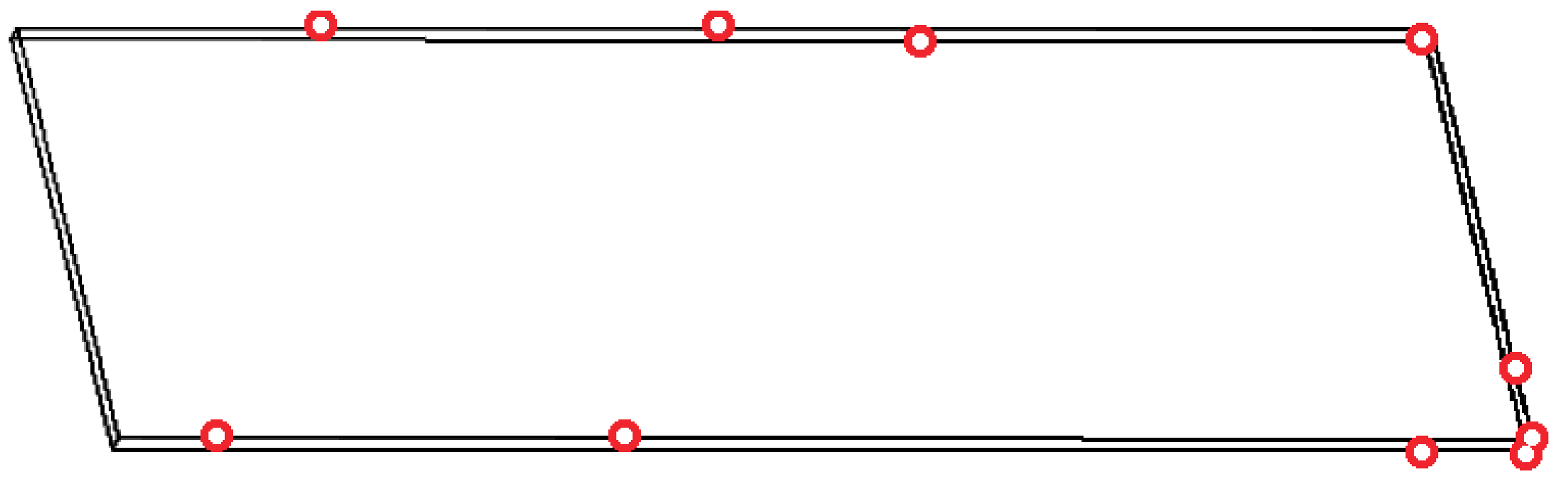
$C_e$ and $C_d$ are weight factors, $\boldsymbol{e}$ and $\boldsymbol{q}$ are numerical strains and displacements and $\boldsymbol{e}^{\varepsilon}$ and $\boldsymbol{q}^{\varepsilon}$ are sensor data.
The error functional is minimized by taking the derivatives with respect to the structural degrees of freedom. The resulting system of linear equations is solved with Gaussian elimination, similar to the classical FE approach. The strains are then calculated from the displacements.

## Set-up

The plate consists of a clamped aluminum cantilever plate under a point bending load as shown in the figure below.

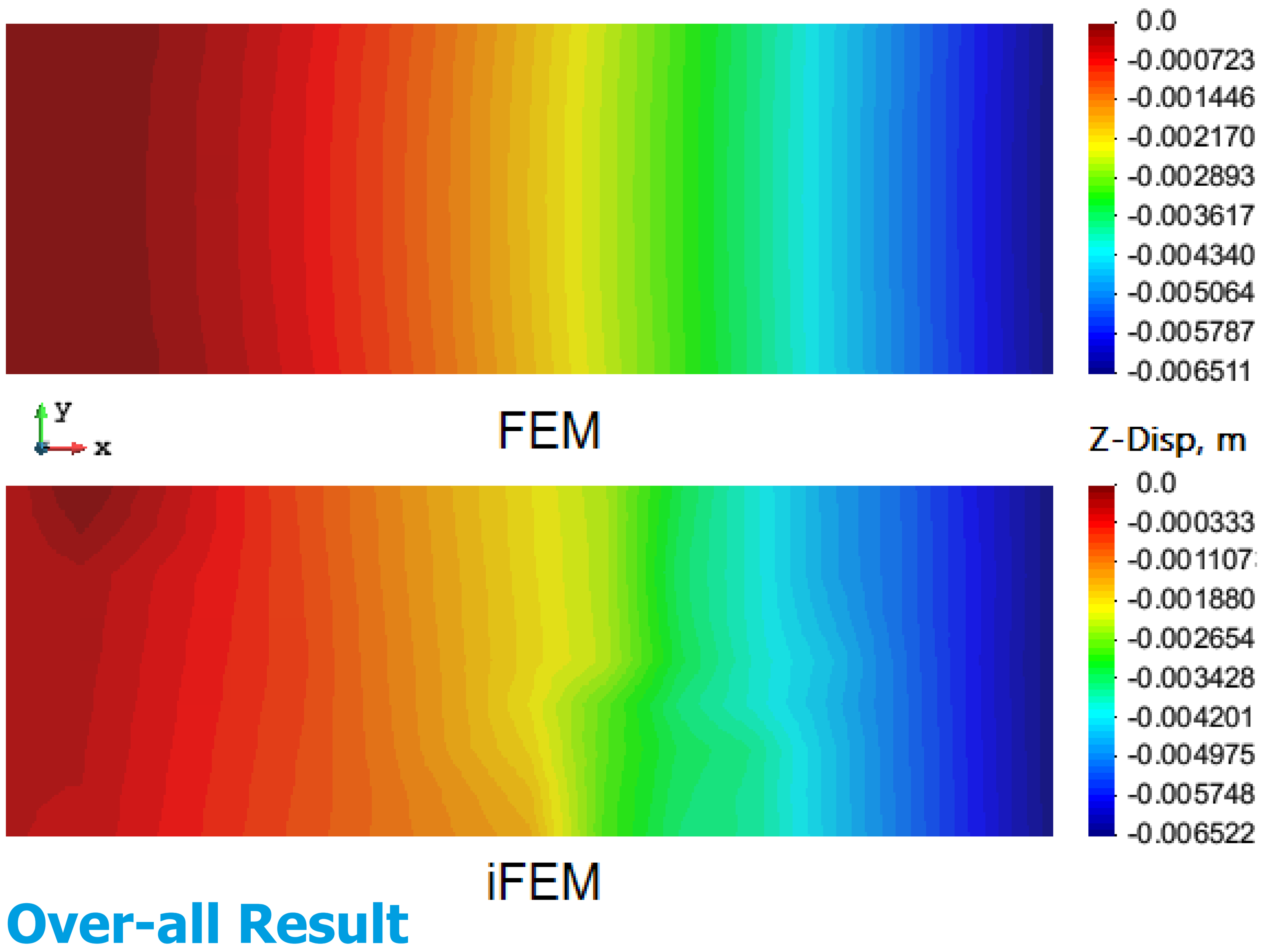



The displacement sensors were placed semi-randomly, avoiding clustering. This results in most sensors being near the edges.



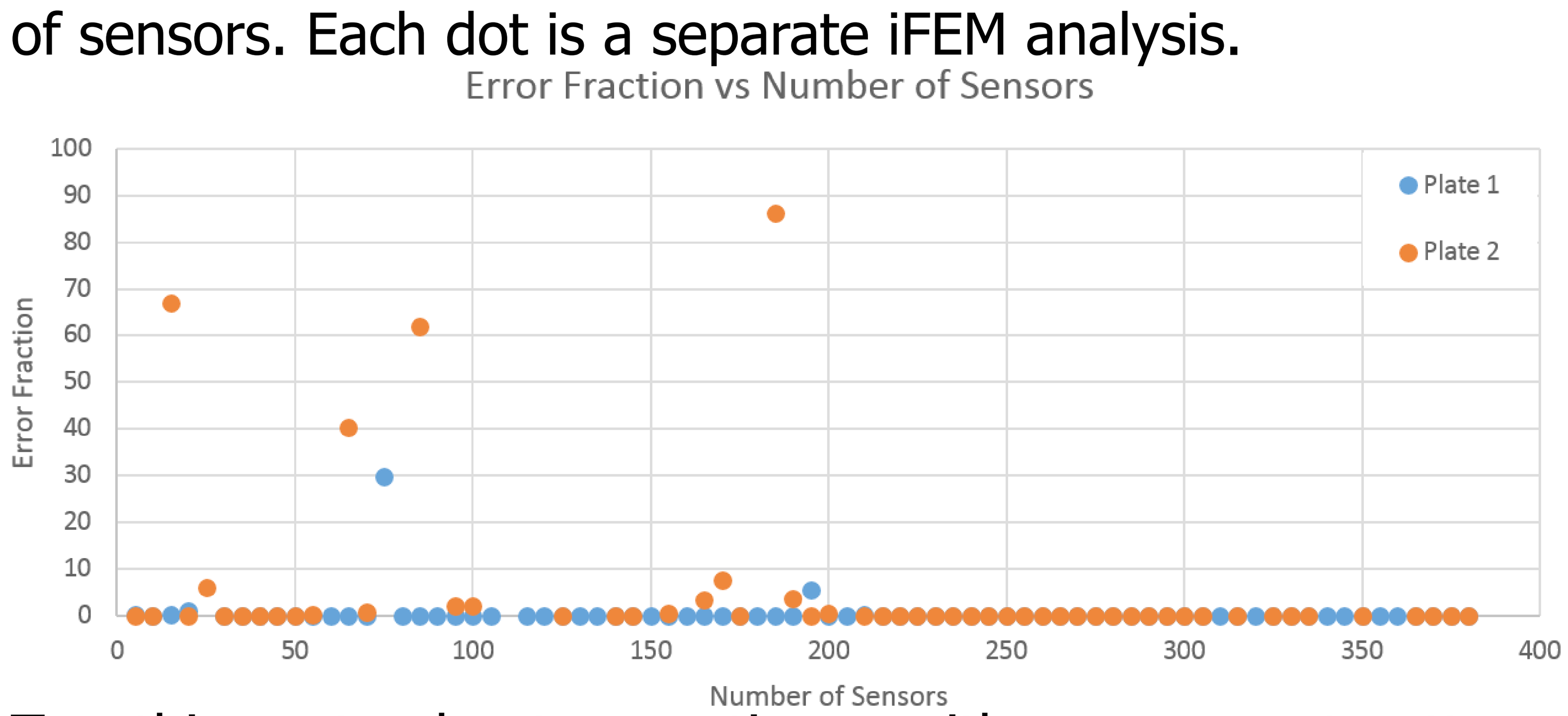
## Result

FEA and iFEM results are shown for a point-loaded cantilever plate. The iFEM analysis used 10 sensors. The maximum deflection has an error of 0.17%, compared to 0.4% with 28 sensors (Kefal et al. 2016). The distortion on the left is due to the optimization focussing on areas with large displacements.




## Over-all Result

The value of the error functional is plotted against the number of sensors. Each dot is a separate iFEM analysis.




Two things stand out: sometimes, with no apparent pattern, a highly inaccurate result is obtained. Second, even with quite a small number of sensors, an accurate estimate of the displacements can be obtained for a simple load case and a simple structure.

## Conclusion

The new iFEM algorithm results were compared to those found in the literature. While the new approach can achieve greater accuracy with fewer sensors than the results presented in the literature, it also shows a lack of reliability, which is believed to be due to the random nature of the sensor placement and the interpolation technique that was utilized.

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