SWISS FEDERAL INSTITUTE OF TECHNOLOGY (EPFL)
School of Architecture, Civil and Environmental Engineering (ENAC)
Applied Computing and Mechanics Laboratory (IMAC)

Project Report
Adaptive Structure Prototype

Project supervisors	**Prof. Ian Smith** **Dr. Gennaro Senatore**
Project assistant	**Arka P. Reksowardojo**
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Submitted by
Apoorv Srivastava
Civil Engineering Undergraduate
IIT Bombay

Activities and progress during the project

- Initially, I read several research papers on the idea behind the design and control of the adaptive structures. I learned about the all-in-one and nested formulation of the problem and particularly followed the nested approach of handling the problem which involved embodied energy optimization, actuator layout optimization, and operational energy minimization. While doing so, I learned about Simultaneous analysis and design (SAND) method and Integrated force method (IFM). I implemented the algorithm in MATLAB with a small case study to gain a better understanding of the method and learn about several intricacies involved. Once I was through with the implementation of the algorithm with cross-section and forces as design variables, based on another research paper on adaptive structures, I extended The MATLAB code to incorporate nodal-displacements as design variables so as to achieve optimum shape under the given loading conditions along with cross-section and forces.
- Following the implementation of the algorithm in MATLAB I worked briefly on the GUI implementation in the Synthesis of Structures code repository where I automated the process of formatting and arranging several figures that appear on screen while executing the program. This involved docking all the figures that appear on screen while executing the program and also saving and formatting the figure to a certain style based on the user input. Through this activity, I gained further understanding of object-oriented coding in MATLAB as well as collaborative programming using a Git platform.
- I started reading the document where the design problem was being examined for its convexity using Jacobians and Hessians of the objective function and constraints. Also, in order to incorporate the control system in real time, the control problem was linearized using gradients of the function. Following this,
    - I corrected the expressions for the Jacobians and Hessians of design and control problems which were not formulated in a standard and consistent representation. I reformulated the shape optimization problem in vector calculus-based representation using denominator layout system. Through this activity, I also learned about the non-convexity of the shape optimization problem.
    - I updated the objective function for the control problem (previously, the sum of the difference of member lengths before and after optimization) to the

sum of the square of the difference between member lengths before and after control which ensured that the member length changes will not cancel out each other if some of them are in compression and other in tension. With the new formulation, the objective function for the control problem has a better physical significance.

  - Subsequently, I implemented the non-linear control problem in MATLAB and solved it using non-linear algorithms, namely Simple Quadratic Programming (SQP) and Interior-point method (IPM). I benchmarked the code with a simple case study carried out previously by Arka. The results were well within the margin of error.

  - I examined the objective function and constraints for convexity-concavity of the function and visualized them to obtain an idea about the location of the optimum point and to get a general idea of binding constraints.

  - I implemented the linearized version of the control problem using derivatives of the objective function and the constraints. The result obtained using the linearized version lie very close to the solution obtained by Arka and solution converges very close to the optimum point after a small number of iterations.

- I examined the closed-form solution of the shape optimization problem based on the Karush-Kuhn-Tucker optimality criterion. With some appropriate assumptions, a closed-form solution was obtained. The closed-form solution matches very well with the solution obtained using SQP, IPM, and linearization. Through this, we gained an insight into the quality of the solution obtained through the proposed formulation of shape optimization.

- I helped Arka in the lab in assembling and testing the prototype. I learned about communication pathways between computer and sensors and actuators as well as a general overview of the control algorithm which will control the structure. I also acquired hands-on experience of working in a lab. Through this activity,

  - I gained a general understanding of the CAN bus protocol which handles the communication between the computing unit and actuators by getting involved in the process of cabling and electrical assembly.

  - I gained a general understanding of stress measurement employing strain-based sensors by getting involved in the testing of the instrumented structural members.

Remarks from the project supervisors:

Remarks from the project assistant: