Active Learning Activities in Structural Model Updating

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Abstract

Numerical models of structural systems (i.e. finite element models)providing valuable information for the design of new structural systems such as bridges and buildings. However, the literature shows that the same numerical techniques might not be successful at modeling the behavior of existing structures. For example, Zhang et al [1] compared the natural frequencies of numerical models of the Kap Shui Mun Bridge and those estimated experimentally and found differences of up to 17%. Model updating techniques are used to improve these models based on experimental data. Significant research has been performed in model updating in the last decade. However, these new modeling techniques have not been widely incorporated into curricular activities in graduate and undergraduate education. This paper discusses effort in the development of a course focused in model updating using the Environments For Fostering Effective Critical Thinking (EFFECTs) framework. In particular, this paper discusses the active learning (AL) exercises used during the course.

Introduction

The fast development of electronics during the last couple of decades has drastically reduced the cost of sensors and data acquisition systems that can be used to instrument structural systems. This has enabled data collection from a number of structural systems and highlighted the need for the development of new modeling techniques that allows the use of this experimental data in the analysis of existing structures. Model updating techniques can be used to enhance numerical models using experimental data. Unfortunately, these new methodologies are not typical in Civil Engineering undergraduate education. The majority of the Civil Engineering programs do not prepare their undergraduate students to understand the capabilities and limitations of sensors and data acquisition systems, even though they might use these tools in their professional life. Furthermore, students might not be aware of the potential uses of the data collected by the sensors.

This paper discusses efforts for the development of a course in the area of model updating. The course uses the EFFECTs pedagogical framework consisting of [2] : i) a decision worksheet asking students to estimate the solution to an engineering problem, ii) active learning activities to introduce students to the material needed to correctly answer the driving question, iii) reflective exercises asking students to reflect on the material learned in class and revise the answer to the driving question, and iv) a final report encouraging students to re-evaluate the solution of the engineering problem. Decision worksheets are not graded to encourage students to express their knowledge. Each AL exercise addresses key concepts to provide an acceptable solution to the driving question. Therefore, assessment of individual concepts is performed after each AL exercises using homework assignments and at the end of the EFFECT with a final project. The final project discusses the final engineering solution to the driving question and a reflection on their learning.

EFFECTs are developed in stages. Key concepts are identifying during the first developmental stage. AL exercises are designed to help students understand these concepts. Later stages include identify a particular engineering problem, give context to the problem, design a decision a driving question and a decision worksheet. This paper focuses in the AL exercises designed for the course in Model Updating (first phase of EFFECT development). More information about EFFECTs, including all educational material required to deploy an EFFECT can be found online at http://sdii.ce.sc.edu/effects.

Course description

The Structural Modeling course is a 500 level course for graduate and undergraduate students at the department of Civil and Environmental Engineering at the University of South Carolina. Structural analysis is a pre-requisite for the course. In addition, students are encouraged to have taken statistics for engineers but it is not a pre-requisite. Students were assessed based on three components i) participation on class exercises, ii) three small projects, and iii) individual exams. The material described here was used in the Fall 2012 semester, when the class was overhauled to include concepts in sensing and model updating. The objectives of the course are to i) learn the capabilities and limitations of instrumentation in structural systems, ii) learn fundamentals in structural modeling and iii) learn fundamentals in model updating. The class was taught within the context of structural dynamics although the concepts can be applied to other areas of engineering. The course was mostly populated with senior undergraduate students (7 students). In addition, one faculty from another department, one visiting researcher and two senior graduate students attended most classes but were not registered for the course. One freshman graduate student was enrolled in the course. The course was divided in three main topics: i) fundamentals of sensing systems, ii) structural modeling, and iii) fundamentals of model updating. Key concepts on how sensor and data acquisition systems work are discussed in the first part. This includes potential issues with data collection such as aliasing, quantization and overloading in data acquisition systems. The second part of the class is the shortest part of the course and it focuses in performing dynamic analysis of a structural system. This part of the course is intended to include only practical applications of structural vibrations to allow students to update the dynamic models. This short section of the class is needed because a course in structural vibrations is not a pre-requisite for the class. Finally, the last section discusses model updating from a deterministic and a probabilistic stand point.

Active learning modules

Two of the AL exercises used in the class are discussed in detail in this section. The first AL activity looks at explaining the consequences of aliasing when signals are converted from analog to digital in data acquisition systems. Aliasing is a phenomenon that occurs when a signal is collected and appears to be at a lower frequency that it really is. This usually occurs when data is acquired at a lower sampling frequency than indicated by the Nyquest sampling theorem. This theorem requires a signal to be sampled at a sampling frequency twice its frequency or higher. The second AL module illustrates how Bayes theorem [3] can be used to provide an estimation of a particular quantity with a limited number of experiments.

Aliasing

Aliasing is usually a different concept to convey to students that are not familiar with frequency representation of signals. This AL exercise is designed to be performed after the concepts of aliasing are discussed in the class as a way to convey the consequences of an aliased signal. The AL exercise starts by telling students that a data acquisition system has been setup to collect a sinusoidal signal. The graph shown in Figure 1 is provided where the "*" indicate the data collected by the data acquisition system. The task is to estimate the frequency of the signal in

Hz. Students are given 2 minutes to perform a quick estimation independently. Then, they are organized in groups of 3 to discuss their findings. Finally, each group reports their findings to the overall class. After students discuss their findings the plot shown in Figure 2 is provided showing the actual signal and the sampled points. Students are asked to verify if the parameter of the data acquisition system comply with the Nyquest sampling theorem for this particular signal and discuss in groups about the exercise.

All students in class estimated the frequency of the signal to be 1/10 Hz using the information from the first plot. The reason given by students is that the plot clearly shows one cycle in 10 seconds.

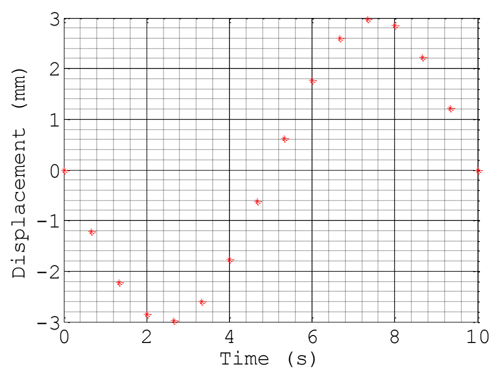


Figure 1. Aliasing AL exercise - Handout 1

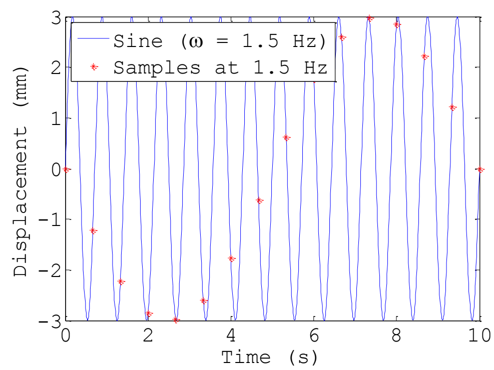


Figure 2. Aliasing AL exercise - Handout 2

Students were able to identify that the sampling frequency does not comply with the Nyquest sampling theorem and gave a better explanation about the effects of Aliasing after the second page was provided. Student feedback on this activity indicates that the AL exercise was valuable to provide an explanation about why aliasing is a potential problem in data acquisition systems. Furthermore, students indicated that the group discussion allowed them to better understand the concept of aliasing and its importance.

Bayes Theorem

Bayes theorem is used for a number of applications in model updating. The seminar papers of Beck and Katafygiotis [4] and Katafygiotis and Beck [5] illustrate how Bayes theorem can be used to estimate the parameter of structural models with limited experimental information. Bayes theorem can be written using the equation [3]:

$$P(\theta|D) = k^{-1}P(\theta)P(D|\theta)$$

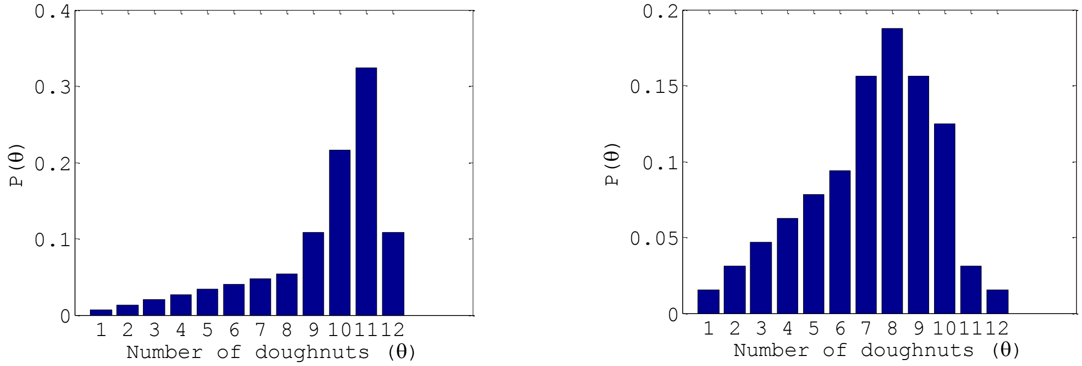
where θ is the structural parameter that will be updated, D is the experimental data and k is a normalization constant. $P(\theta)$ is the prior probability distribution function (PDF) of the structural parameters. This PDF is formulated by the engineer or analyst based on any prior information that he/she might have available. $P(D|\theta)$ is the likelihood of the experimental data D given a particular set of structural parameters θ. In structural engineering Bayes can be used to determine structural parameters such as young modulus based on dynamic characteristics of the structure or to determine the remaining life of a steel element based on data collected from acoustic emission sensors. Students usually have difficulties understanding how to formulate a prior PDF and what the likelihood really means. This AL exercise focuses on providing a simple example where this can understood.

This AL exercise was used in the class after the theory and some numerical examples about Bayes model updating were discussed. At the beginning of the class the instructor arrives with a box of doughnuts (dozen doughnut box) and asks students to estimate the probability that ten students in the room can have at least one doughnut. The box used for the Fall 2012 class had 10 doughnuts. However, there are some rules to follow: i) students cannot open the box, ii) the data collected from the specimen is the approximate weight of the box, iii) only one data point is available (i.e. only one student gets to approximate the weight of the box). The last item symbolizes constrains that engineers have to perform experiments on structural systems due to cost and time. The instructor also gave students some information about his preferences for doughnuts so they can formulate a prior probability mass function (PMF). This is:

1. The instructor bought the box of doughnuts that morning. They were hot.
2. The instructor really like doughnuts and has been seeing eating one or two doughnuts during presentations.
3. The instructor was seeing in the lab that morning. There is a possibility that he might have offered doughnuts to his graduate students. There are 4 graduate students and 3 undergraduate students in his lab but not everyone might have been there.

Students divided in two groups and asked to formulate the prior PMF. Figure 3 shows the prior PMF of both groups. Based on their prior PMF the probability that ten students will have at least one doughnut was calculated as $P(\theta \geq 10) = 0.65$ for group 1 and $P(\theta \geq 10) = 0.17$ for group 2.

It is important for the instructor to make a connection between this example and an actual engineering application. After each group described their prior PMF the instructor described a problem where the number of concrete specimens tested would fail. A similar procedure could be done to formulate a prior PMF for the engineering problem.

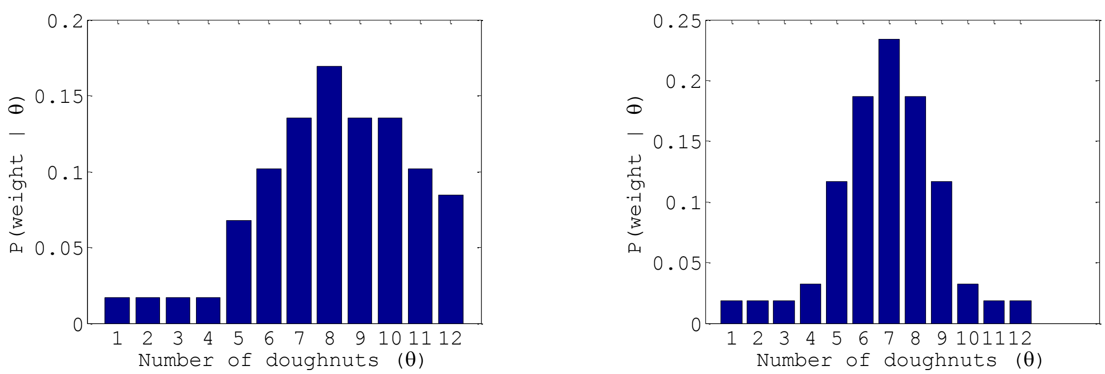


a. Group 1 b. Group 2

Figure 3. Prior PMF

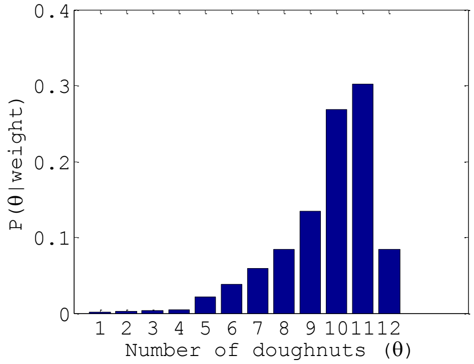
The next step in the AL exercise was to formulate a likelihood function. In the case of the doughnuts the experimental data that can be obtained is not the number of doughnuts itself but the approximate weight of the box. Therefore, the likelihood function would be $P(weight|number\ of\ doughnuts)$. Each student selected one student that held the box of doughnuts and estimated the weight. Based on the estimation of the weight students would have to determine the probability of the weight given 1, 2, … 12 doughnuts and report back their liklihood. Figure 4 shows the reported likelihood function for both groups. The student of group 1 estimated that the box had probably more than eight doughnuts while the student from group 2 believe that it was not very likely that the box had more than 10 doughnuts. Unlike classical probability, Bayes does not require a large number of measurements. Therefore, the number of students in the class does not affect the teaching of the material. The use of a scale to measure the actual weight of the box is recommended for future implementations of this AL exercise. Using a scale is similar to what is done in structural model updating where a sensor is used to measure a physical quantity. In addition, this will reduce measurement error that might be created by the student estimation of the weight (i.e. group 2).

The posterior PMF was calculated based on this information for both groups and is shown in Figure 5. The probability of the number of doughnuts being more or equal to 10 with the updated PMF is $P(\theta \geq 10|D) = 0.66$ for group 1 and $P(\theta \geq 10|D) = 0.04$ for group 2. The

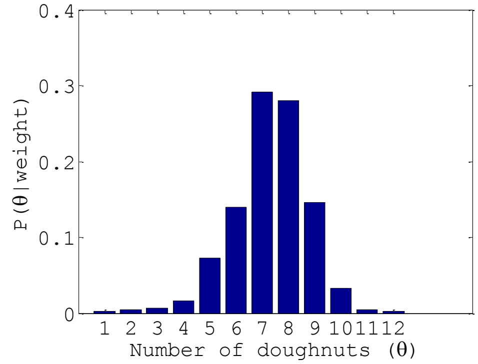


a. Group 1 b. Group 2

Figure 4. Likelihood



a. Group 1



b. Group 2

Figure 5. Posterior PMF

PMF of the first group shifted towards the correct value (10 doughnuts) but the PMF of group 2 shifted downwards because of the bias on the estimation of the weight of the box.

Students indicated that this AL exercise helped them understand how Bayes theory works. In particular, in the calculation of the prior PDF (or PMF).

This exercise was followed by a model updating exercise where the stiffness of a two degree of freedom structure (shear building) is updated based on experimental data from vibration analysis. The instructor built upon this active learning exercise by indicating the similarities between the two problems. For example, any prior information that the analyst might have about the stiffness of the structure (e.g. material characteristics) is equivalent to the prior knowledge that students had about the number of doughnuts (e.g. the box can only hold a dozen doughnuts, and the instructor might have eaten one or more doughnuts).

Conclusions

This paper discusses two AL exercises that were developed and used in a course in model updating. The AL exercises focus on two concepts that were identified by faculty as difficult to understand. The first discusses the phenomenon of quantization and the second concepts related with Bayes inference. A small number of students were enrolled in the course, making it difficult to perform a rigorous assessment of the AL exercises. However, student feedback indicates that the exercises helped them understand these two concepts.

Acknowledgements

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Bibliography

1. Zhang, Q.W., T.Y.P. Chang, and C.C. Chang, *Finite-Element Model Updating for the Kap Shui Mun Cable-Stayed Bridge*. Journal of Bridge Engineering, 2001. **6**(4): p. 285-293.

2. Caicedo, J.M., et al., *Assessment of Environments for Fostering Effective Critical Thinking (EFFECTs) on a first-year civil engineering course*, in *ASEE annual meeting*2009: Austin, TX.

3. Ang, A.H.-S. and W.H. Tang, *Probability concepts in engineering : emphasis on applications in civil & environmental engineering*. 2nd ed. 2007, New York: Wiley. xiii, 406 p.

4. Beck, J.L. and L.S. Katafygiotis, *Updating Models and Their Uncertainties. I: Bayesian Statistical Framework.* Journal of Engineering Mechanics, 1998. **124**(4): p. 455-461.

5. Katafygiotis, L.S. and J.L. Beck, *Updating Models and Their Uncertainties. II: Model Identifiability*. Journal of Engineering Mechanics, 1998. **124**(4): p. 463-467.