

Deep Learning Architectures for Structural Damage Detection; Project Report: CS 7643

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Abstract

Climate change has led to increased incidences of hurricanes, extreme heat, flooding, and wildfires within our communities. These natural hazards in addition to earthquakes necessitate major changes to protect structures from these extreme loading events or mitigate their effects in the aftermath of natural disasters by moving towards more resilient structural solutions. While resilient structural design methodologies accounts for the probability of these extreme loading events, the need to balance the economics of the structure with the risk of structural failure under these extreme events, and possibly provide solutions for immediate recovery and occupancy of infrastructures in case of major events, is deemed crucial. Hence, rapid structural damage detection is an extremely useful tool to achieve resilient structures and communities. Owing to artificial intelligence (AI) and machine learning (ML) algorithms deep learning (DL) applications in image processing, structural health monitoring (SHM) in this context has grown extensively in recent years. In this project, we aim to contribute to this area of engineering by applying what we have learned in the CS-7643 DL course.

1. Introduction/Background/Motivation

In this project, the main objective is to combine the available DL methods learnt in the course with the SHM application, specifically post-disaster structural damage recognition. The dataset created by the University of California Berkeley will be used as the main reference, called herein Structural ImageNet. The UC Berkeley research has applied only VGGNet architecture, while in this project, we are aiming to apply several other convolutional neural networks (CNN) architectures to study the Structural ImageNet tasks replacing the already used VGGNet, for instance, GoogleNet (Szegedy et al., 2015) and ResNet (He et al., 2016). Also, in the UC Berkeley research, instead

of training deep CNN from scratch, deep Transfer Learning (TL) with VGG pretrained model is implemented, and feature extractor and fine-tuning as two TL strategies were introduced. With an increasing number of images, we are aiming to conduct the training process from scratch (i.e., without any pre-trained model), which is expected to have better performance. Complex recognition can be pursued, such as multiclass classification including the identification of many damage levels and multiple damage types for practical and broader use. To provide more useful information for real SHM applications, damage localization and quantification can be investigated additionally, if time allows.

The abbreviated employed “Structural ImageNet” is a large-scale open-sourced structural image database called the “PEER (Pacific Earthquake Engineering Research Center) Hub ImageNet (PHI-Net)”. As of November 2019, this PHI-Net dataset contains 36,413 images with multiple attributes for the following baseline recognition tasks: scene-level classification, structural component type identification, crack existence check, and damage-level detection. According to the UC researchers at Berkeley, there is no other open-sourced structural image dataset with multi-attribute labels and this volume of images in the vision-based SHM area. It is believed that this image dataset and its corresponding detection tasks and framework will provide the necessary benchmark for future studies of DL in vision-based SHM. Here is the link to the dataset: <https://apps.peer.berkeley.edu/phi-net/> The dataset has been divided into eight subsets of scene level, damage state, spalling condition, material type, collapse mode, component type, damage level, and damage type (publicly available).

(5 points) What did you try to do? What problem did you try to solve? Articulate your objectives using absolutely no jargon.

(5 points) How is it done today, and what are the limits of current practice?

(5 points) Who cares? If you are successful, what difference will it make?

(5 points) What data did you use? Provide details about your data, specifically choose the most important aspects of your data mentioned [here](#). You don't have to choose all of them, just the most relevant.

2. Approach

(10 points) What did you do exactly? How did you solve the problem? Why did you think it would be successful? Is anything new in your approach?

(5 points) What problems did you anticipate? What problems did you encounter? Did the very first thing you tried work?

Important: Mention any code repositories (with citations) or other sources that you used, and specifically what changes you made to them for your project.

3. Experiments and Results

(10 points) How did you measure success? What experiments were used? What were the results, both quantitative and qualitative? Did you succeed? Did you fail? Why? Justify your reasons with arguments supported by evidence and data.

Important: This section should be rigorous and thorough. Present detailed information about decision you made, why you made them, and any evidence/experimentation to back them up. This is especially true if you leveraged existing architectures, pre-trained models, and code (i.e. do not just show results of fine-tuning a pre-trained model without any analysis, claims/evidence, and conclusions, as that tends to not make a strong project).

4. Other Sections

You are welcome to introduce additional sections or subsections, if required, to address the following questions in detail.

(5 points) Appropriate use of figures / tables / visualizations. Are the ideas presented with appropriate illustration? Are the results presented clearly; are the important differences illustrated?

(5 points) Overall clarity. Is the manuscript self-contained? Can a peer who has also taken Deep Learning understand all of the points addressed above? Is sufficient detail provided?

(5 points) Finally, points will be distributed based on your understanding of how your project relates to Deep Learning. Here are some questions to think about:

What was the structure of your problem? How did the structure of your model reflect the structure of your problem?

What parts of your model had learned parameters (e.g.,

convolution layers) and what parts did not (e.g., post-processing classifier probabilities into decisions)?

What representations of input and output did the neural network expect? How was the data pre/post-processed? What was the loss function?

Did the model overfit? How well did the approach generalize?

What hyperparameters did the model have? How were they chosen? How did they affect performance? What optimizer was used?

What Deep Learning framework did you use?

What existing code or models did you start with and what did those starting points provide?

Briefly discuss potential future work that the research community could focus on to make improvements in the direction of your project's topic.

5. Work Division

Please add a section on the delegation of work among team members at the end of the report, in the form of a table and paragraph description. This and references do **NOT** count towards your page limit. An example has been provided in Table 1.

Student Name	Contributed Aspects	Details
Hossein Daneshvar	Data Creation and Implementation	Scraped the dataset for this project and trained the CNN of the encoder. Implemented attention mechanism to improve results.
Mahshid Jafar Pour	Implementation and Analysis	Trained the LSTM of the encoder and analyzed the results. Analyzed effect of number of nodes in hidden state. Implemented Convolutional LSTM.

Table 1. Contributions of team members.

6. Miscellaneous Information

The rest of the information in this format template has been adapted from CVPR 2020 and provides guidelines on the lower-level specifications regarding the paper’s format.

6.1. Language

All manuscripts must be in English.

6.2. Paper length

Papers, excluding the references section, must be no longer than six pages in length. The references section will not be included in the page count, and there is no limit on the length of the references section. For example, a paper of six pages with two pages of references would have a total length of 8 pages.

6.3. The ruler

The L^AT_EX style defines a printed ruler which should be present in the version submitted for review. The ruler is provided in order that reviewers may comment on particular lines in the paper without circumlocution. If you are preparing a document using a non-L^AT_EX document preparation system, please arrange for an equivalent ruler to appear on the final output pages. The presence or absence of the ruler should not change the appearance of any other content on the page. The camera ready copy should not contain a ruler. (L^AT_EX users may uncomment the `\cvprfinalcopy` command in the document preamble.) Reviewers: note that the ruler measurements do not align well with lines in the paper — this turns out to be very difficult to do well when the paper contains many figures and equations, and, when done, looks ugly. Just use fractional references (e.g. this line is 095.5), although in most cases one would expect that the approximate location will be adequate.

6.4. Mathematics

Please number all of your sections and displayed equations. It is important for readers to be able to refer to any particular equation. Just because you didn’t refer to it in the text doesn’t mean some future reader might not need

to refer to it. It is cumbersome to have to use circumlocutions like “the equation second from the top of page 3 column 1”. (Note that the ruler will not be present in the final copy, so is not an alternative to equation numbers). All authors will benefit from reading Mermin’s description of how to write mathematics: <http://www.pamitc.org/documents/mermin.pdf>.

Finally, you may feel you need to tell the reader that more details can be found elsewhere, and refer them to a technical report. For conference submissions, the paper must stand on its own, and not *require* the reviewer to go to a techreport for further details. Thus, you may say in the body of the paper “further details may be found in [?]”. Then submit the techreport as additional material. Again, you may not assume the reviewers will read this material.

Sometimes your paper is about a problem which you tested using a tool which is widely known to be restricted to a single institution. For example, let’s say it’s 1969, you have solved a key problem on the Apollo lander, and you believe that the CVPR70 audience would like to hear about your solution. The work is a development of your celebrated 1968 paper entitled “Zero-g frobnication: How being the only people in the world with access to the Apollo lander source code makes us a wow at parties”, by Zeus *et al.*

You can handle this paper like any other. Don’t write “We show how to improve our previous work [Anonymous, 1968]. This time we tested the algorithm on a lunar lander [name of lander removed for blind review]”. That would be silly, and would immediately identify the authors. Instead write the following:

We describe a system for zero-g frobnication. This system is new because it handles the following cases: A, B. Previous systems [Zeus et al. 1968] didn’t handle case B properly. Ours handles it by including a foo term in the bar integral.

...

The proposed system was integrated with the Apollo lunar lander, and went all the way to the moon, don’t you know. It displayed the following behaviours which show how well we solved cases A and B: ...

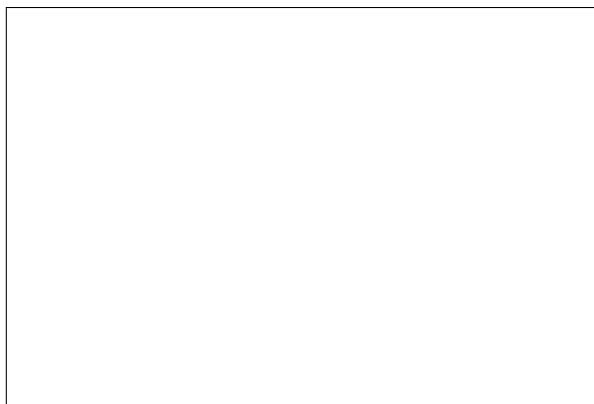


Figure 1. Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

As you can see, the above text follows standard scientific convention, reads better than the first version, and does not explicitly name you as the authors. A reviewer might think it likely that the new paper was written by Zeus *et al.*, but cannot make any decision based on that guess. He or she would have to be sure that no other authors could have been contracted to solve problem B.

FAQ

Q: Are acknowledgements OK?

A: No. Leave them for the final copy.

Q: How do I cite my results reported in open challenges?

A: To conform with the double blind review policy, you can report results of other challenge participants together with your results in your paper. For your results, however, you should not identify yourself and should not mention your participation in the challenge. Instead present your results referring to the method proposed in your paper and draw conclusions based on the experimental comparison to other results.

6.5. Miscellaneous

Compare the following:

`$conf_a$` *conf_a*
`conf_a` *conf_a*

See The T_EXbook, p165.

The space after *e.g.*, meaning “for example”, should not be a sentence-ending space. So *e.g.* is correct, *e.g.* is not. The provided `\eg` macro takes care of this.

When citing a multi-author paper, you may save space by using “et alia”, shortened to “*et al.*” (not “*et. al.*” as “*et*” is a complete word.) However, use it only when there are three or more authors. Thus, the following is correct: “Frobination has been trendy lately. It was introduced

by Alpher [?], and subsequently developed by Alpher and Fotheringham-Smythe [?], and Alpher *et al.* [?].”

This is incorrect: “... subsequently developed by Alpher *et al.* [?] ...” because reference [?] has just two authors. If you use the `\etal` macro provided, then you need not worry about double periods when used at the end of a sentence as in Alpher *et al.*

For this citation style, keep multiple citations in numerical (not chronological) order, so prefer [?, ?, ?] to [?, ?, ?].

6.6. Formatting your paper

All text must be in a two-column format. The total allowable width of the text area is $6\frac{7}{8}$ inches (17.5 cm) wide by $8\frac{7}{8}$ inches (22.54 cm) high. Columns are to be $3\frac{1}{4}$ inches (8.25 cm) wide, with a $\frac{5}{16}$ inch (0.8 cm) space between them. The main title (on the first page) should begin 1.0 inch (2.54 cm) from the top edge of the page. The second and following pages should begin 1.0 inch (2.54 cm) from the top edge. On all pages, the bottom margin should be 1-1/8 inches (2.86 cm) from the bottom edge of the page for 8.5 × 11-inch paper; for A4 paper, approximately 1-5/8 inches (4.13 cm) from the bottom edge of the page.

6.7. Margins and page numbering

All printed material, including text, illustrations, and charts, must be kept within a print area $6\frac{7}{8}$ inches (17.5 cm) wide by $8\frac{7}{8}$ inches (22.54 cm) high.

6.8. Type-style and fonts

Wherever Times is specified, Times Roman may also be used. If neither is available on your word processor, please use the font closest in appearance to Times to which you have access.

MAIN TITLE. Center the title 1-3/8 inches (3.49 cm) from the top edge of the first page. The title should be in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two blank lines after the title.

AUTHOR NAME(s) and **AFFILIATION(s)** are to be centered beneath the title and printed in Times 12-point, non-boldface type. This information is to be followed by two blank lines.

The **ABSTRACT** and **MAIN TEXT** are to be in a two-column format.

MAIN TEXT. Type main text in 10-point Times, single-spaced. Do NOT use double-spacing. All paragraphs should be indented 1 pica (approx. 1/6 inch or 0.422 cm). Make sure your text is fully justified—that is, flush left and flush right. Please do not place any additional blank lines between paragraphs.

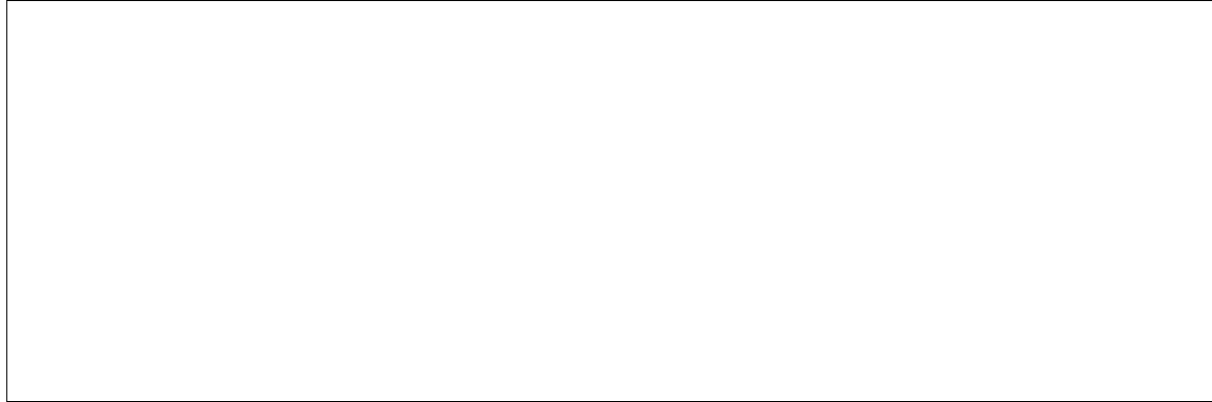


Figure 2. Example of a short caption, which should be centered.

Figure and table captions should be 9-point Roman type as in Figures 1 and 2. Short captions should be centred. Callouts should be 9-point Helvetica, non-boldface type. Initially capitalize only the first word of section titles and first-, second-, and third-order headings.

FIRST-ORDER HEADINGS. (For example, **1. Introduction**) should be Times 12-point boldface, initially capitalized, flush left, with one blank line before, and one blank line after.

SECOND-ORDER HEADINGS. (For example, **1.1. Database elements**) should be Times 11-point boldface, initially capitalized, flush left, with one blank line before, and one after. If you require a third-order heading (we discourage it), use 10-point Times, boldface, initially capitalized, flush left, preceded by one blank line, followed by a period and your text on the same line.

6.9. Footnotes

Please use footnotes¹ sparingly. Indeed, try to avoid footnotes altogether and include necessary peripheral observations in the text (within parentheses, if you prefer, as in this sentence). If you wish to use a footnote, place it at the bottom of the column on the page on which it is referenced. Use Times 8-point type, single-spaced.

6.10. References

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [?]. Where appropriate, include the name(s) of editors of referenced books.

6.11. Illustrations, graphs, and photographs

All graphics should be centered. Please ensure that any point you wish to make is resolvable in a printed copy of

¹This is what a footnote looks like. It often distracts the reader from the main flow of the argument.

Method	Frobnability
Theirs	Frumpy
Yours	Frobbly
Ours	Makes one's heart Frob

Table 2. Results. Ours is better.

the paper. Resize fonts in figures to match the font in the body text, and choose line widths which render effectively in print. Many readers (and reviewers), even of an electronic copy, will choose to print your paper in order to read it. You cannot insist that they do otherwise, and therefore must not assume that they can zoom in to see tiny details on a graphic.

When placing figures in L^AT_EX, it's almost always best to use `\includegraphics`, and to specify the figure width as a multiple of the line width as in the example below

```
\usepackage[dvips]{graphicx} ...  
\includegraphics[width=0.8\linewidth]  
{myfile.eps}
```

6.12. Color

Please refer to the author guidelines on the CVPR 2020 web page for a discussion of the use of color in your document.