Self-Driving Car Steering Angle Prediction Based on Image Recognition (Milestone)

Shuyang Du
shuyangd@stanford.edu

Haoli Gui
haoliguo@stanford.edu

Andrew Simpson
asimpso8@stanford.edu

Abstract

Self-driving vehicles have expanded drastically over the last few year. Udacity has release a dataset containing, among other data, a set of images with the steering angle captured during driving. The Udacity challenge aimed to predict steering angle based on only the provided images. We explore different models to perform high quality prediction of steering angles based only images using different deep learning techniques.

1. Introduction

Self-driving vehicles are going to be of enormous economic impact over the coming decade. Creating models that meet or exceed the ability of a human driver could save thousands of lives a year.

Udacity has an ongoing challenge to create an open source self-driving car. In there second challenge Udacity released a dataset of images taken while driving along with the corresponding steering angle and ancillary sensor data for a training set (left, right, and center cameras with interpolated angles based on camera angle). The goal of the challenge was to find a model that, given a image taken while driving, will minimize the RMSE (root mean square error) between what the model predicts and the actual steering angle produced by a human driver.

From this challenge, several top models emerged. The top three teams had an RMSE of approximately 0.055 (a guess of the mean angle, 0, would predict 0.2067).

2. Related Work

NVIDIA released a paper last year "End to End Learning for Self-Driving Cars." In this paper the authors used a relatively basic CNN architecture. The layout of the architecture can be seen in Figure 1. Augmentation of the data collected was found to be important. The authors used artificial shifts and rotations of the training set. Left and right cameras with interpolated steering angles were also incorporated.

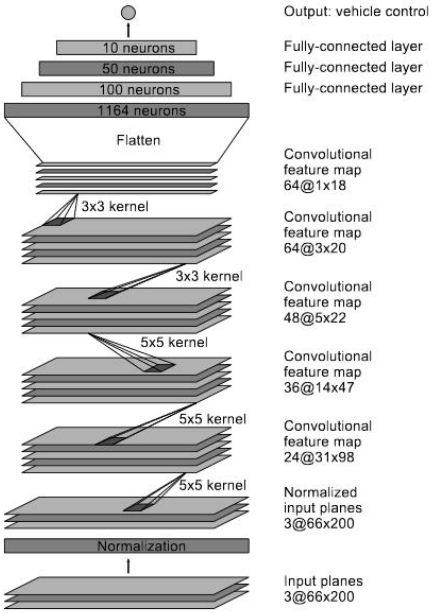

Figure 1. CNN architecture used in [6]. The network contains approximately 27 million connections and 250 thousand parameters.

In the Udacity challenge team Chauffeur placed third with an RMSE of 0.0572. This team used a large pretrained CNN model. This model was then modified to have an output of approximately 3000 features. This output was then passed into a relatively simple LSTM (long short-term memory [7]) network with the best model having a window of 50 images or 2.5 seconds of video.

3. Methods

A potential method is taking the last n frames from the training set allow use of networks using 3D convolutions [8]. Creating an architecture like resnet with these layers may capture important image information between layers. Additionally passing the processed data from this network into an RNN (using LSTM) could allow for knowledge of the previous states to be used to predict the next state of the steering angle. Additional methods that different teams

used that could be used with this approach is to take the difference between frames instead of the raw image data. Transfer learning of a large network would also likely be helpful for model development.

3.1. Data Preprocessing

During experimentation, copying the general structure from [6] with the dataset from Udacity produced poor results. Initially, training data was passed unprocessed into the model. Without any preprocessing, the RMSE on the training set was very low; however, the error on the validation set was worse than passing all zeros in as the output (0.2130 on the validation set). We are currently examining ways to best augment the training set to improve performance on the validation set. One common idea in the different teams was to flip the training on the y axis to account for any turn asymmetry. Adding random shadows, hue changes, rotations, and shifts in the images are being examined along with incorporation images from the left and right cameras. However, using the left and right cameras when using RNNs may not make sense as the angle is interpolated as what the car should do if that image were the front facing camera. Frames that have the steering angle at approximately 0 can be preferentially excluding in favor of frames with larger steering angles.

4. Dataset and Features

paper for presentation in eight pages if it is reviewed in eleven.

5. Experiments, Results, and Discussion

As a baseline, the work from [6] is being reproduced on the dataset from Udacity. A model, using Keras, was constructed that followed the layout from [6]. Currently the results have only produced a result of 0.19 on the validation set. This result is better than guessing all zeros, but is not a competitive score. Further data augmentation is being examined to improve the RMSE on the validation set.

Team Chauffeurs code was examined. In testing this code it was found to have a high RMSE at first, but eventually produced quality results. The core idea of this model can likely be extended to other methods such as 3D convolution with temporal data. This may or may not aid the later LSTM network, which would, by its own architecture, contain temporal information.

In examining these models we think it would be possible to combine different aspects in order to obtain similar or superior results.

6. Conclusion and Future Work

Finding better ways to augment the training dataset allows for an effectively larger training set size, which will help better generalization on the validation and testing sets.

6.1. The ruler

The LaTeX 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-LaTeX 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. (LaTeX 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.

6.2. 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`.

6.3. Blind review

Many authors misunderstand the concept of anonymizing for blind review. Blind review does not mean that one must remove citations to one's own work—in fact it is often impossible to review a paper unless the previous citations are known and available.

Blind review means that you do not use the words "my" or "our" when citing previous work. That is all. (But see below for techreports.)

Saying "this builds on the work of Lucy Smith [1]" does not say that you are Lucy Smith; it says that you are building on her work. If you are Smith and Jones, do not say "as we show in [7]", say "as Smith and Jones show in [7]" and at the end of the paper, include reference 7 as you would any other cited work.

An example of a bad paper just asking to be rejected:

An analysis of the frobnicatable foo filter.

> In this paper we present a performance analysis of our previous paper [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.
>
> [1] Removed for blind review

An example of an acceptable paper:

> An analysis of the frobnicatable foo filter.
>
> In this paper we present a performance analysis of the paper of Smith *et al*. [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.
>
> [1] Smith, L and Jones, C. "The frobnicatable foo filter, a fundamental contribution to human knowledge". Nature 381(12), 1-213.

If you are making a submission to another conference at the same time, which covers similar or overlapping material, you may need to refer to that submission in order to explain the differences, just as you would if you had previously published related work. In such cases, include the anonymized parallel submission [4] as additional material and cite it as

> [1] Authors. "The frobnicatable foo filter", F&G 2014 Submission ID 324, Supplied as additional material `fg324.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 [5]". 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:

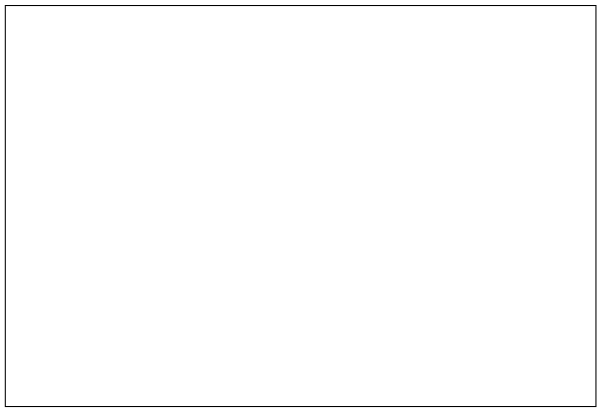

Figure 2. Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

> 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: ...

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: Are acknowledgements OK? No. Leave them for the final copy.

6.4. Miscellaneous

Compare the following:

`$conf_a$`	$conf_a$
`$\mathit{conf}_a$`	conf_a

See The TEXbook, 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: " Frobnication has been trendy lately. It was introduced

by Alpher [1], and subsequently developed by Alpher and Fotheringham-Smythe [2], and Alpher *et al*. [3]."

This is incorrect: "... subsequently developed by Alpher *et al*. [2] ..." because reference [2] 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 [2, 1, 4] to [1, 2, 4].

7. 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.

7.1. Margins and page numbering

All printed material, including text, illustrations, and charts, must be kept within a print area 6-7/8 inches (17.5 cm) wide by 8-7/8 inches (22.54 cm) high. Page numbers should be in footer with page numbers, centered and .75 inches from the bottom of the page and make it start at the correct page number rather than the 4321 in the example. To do this fine the line (around line 23)

```
%\ifcvprfinal\pagestyle{empty}\fi
\setcounter{page}{4321}
```

where the number 4321 is your assigned starting page.

Make sure the first page is numbered by commenting out the first page being empty on line 46

```
%\thispagestyle{empty}
```

7.2. 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.

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

Table 1. Results. Ours is better.

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 and table captions should be 9-point Roman type as in Figures 2 and 3. 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.

7.3. Footnotes

Please use footnotes[1] 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.

7.4. 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 [4]. Where appropriate, include the name(s) of editors of referenced books.

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

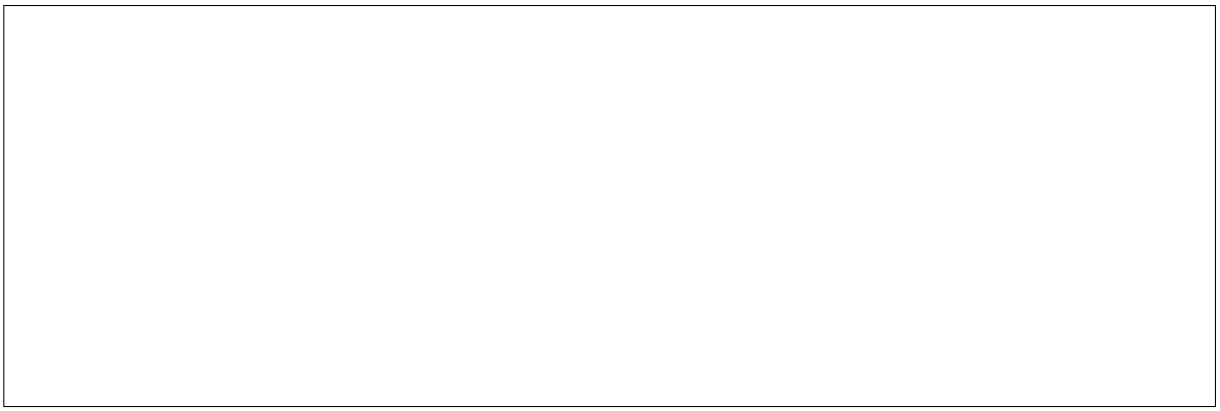

Figure 3. Example of a short caption, which should be centered.

7.5. 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 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 LaTeX, 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}
```

7.6. Color

Please refer to the author guidelines on the CVPR 2015 web page for a discussion of the use of color in your document.

8. Final copy

You must include your signed IEEE copyright release form when you submit your finished paper. We MUST have this form before your paper can be published in the proceedings.

References

[1] A. Alpher. Frobnication. *Journal of Foo*, 12(1):234–778, 2002.

[2] A. Alpher and J. P. N. Fotheringham-Smythe. Frobnication revisited. *Journal of Foo*, 13(1):234–778, 2003.

[3] A. Alpher, J. P. N. Fotheringham-Smythe, and G. Gamow. Can a machine frobnicate? *Journal of Foo*, 14(1):234–778, 2004.

[4] Authors. The frobnicatable foo filter, 2014. Face and Gesture submission ID 324. Supplied as additional material `fg324.pdf`.

[5] Authors. Frobnication tutorial, 2014. Supplied as additional material `tr.pdf`.

[6] M. Bojarski, D. Del Testa, D. Dworakowski, B. Firner, B. Flepp, P. Goyal, L. D. Jackel, M. Monfort, U. Muller, J. Zhang, et al. End to end learning for self-driving cars. *arXiv preprint arXiv:1604.07316*, 2016.

[7] S. Hochreiter and J. Schmidhuber. Long short-term memory. *Neural computation*, 9(8):1735–1780, 1997.

[8] D. Tran, L. Bourdev, R. Fergus, L. Torresani, and M. Paluri. Learning spatiotemporal features with 3d convolutional networks. In *The IEEE International Conference on Computer Vision (ICCV)*, December 2015.