
Performance Optimization of a Convolutional Neural Network for Real-Time Pulse Detection

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Abstract

During CPR, automatically detecting pulse can save precious seconds compared to manual palpation. While devices exist for pulse detection², there are limited options when it comes to rigorous detection algorithms. This paper will explore convolutional neural networks (CNNs) as an option for the real-time binary classification of a pulse reading. Using a pulse wave dataset, we swept several critical hyperparameters, optimizing for accuracy. Our final model has achieved an accuracy of [TODO]%, indicating that the use of CNNs for pulse classification is viable for real-time detection.

1 Input Data

1.1 Dataset Description

The dataset used for this work was collected as part of UBC ECE Capstone Group LS-15's project. It is a series of four second segments, each a time series of pulse data described as sensor values (arbitrary units). Data is sampled at 60Hz, meaning each sample is 240 points in length. A typical sample might look like the plot as shown in figure 1.

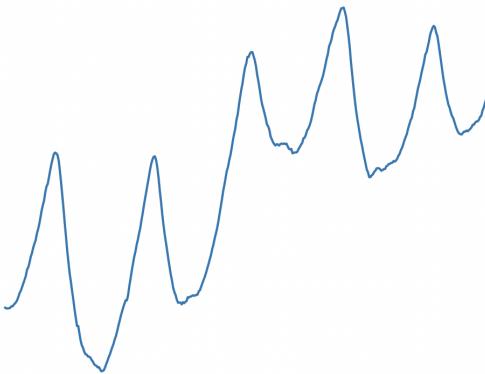


Figure 1: Typical pulse sample

Each data point (four second segment) is labelled by hand as either having, or not having a pulse. The sample in figure 1 would be labelled as having a pulse. Labelling was performed by non-experts, and as such is expected to have some error.

*This is my dog, I like using 'we' on formal papers.

²For example, my capstone group's device.

The dataset comprises of 701 data points, collected in a variety of test conditions. The distribution of the data is shown in figure 2. 61% of data has a pulse, while 39% does not.

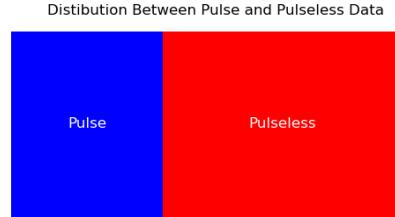


Figure 2: Dataset distribution

Although many samples such as figure 1 may have an easily visible pulse, some samples are more challenging, with spikes created by noise or weak pulse signals.

1.2 Preprocessing

As seen in figure 1, data often has high and low frequency noise that we would like to filter. After flooring the data by setting the lowest value to 0, we apply a band pass filter as seen in figure 3. This passes frequencies from 0.5Hz to 5Hz, which translates to 30 BPM and 300 BPM, considered the possible range for the human heart rate.

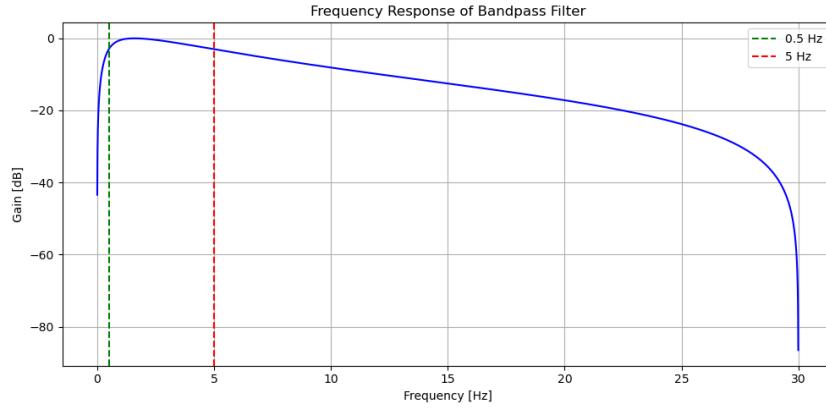


Figure 3: Frequency response of band pass filter

Data often has a strong baseline shift. To eliminate this, we fit a 4th degree polynomial to the data, and then remove that, treating it as a baseline. An example of a fitted polynomial can be found in figure 4

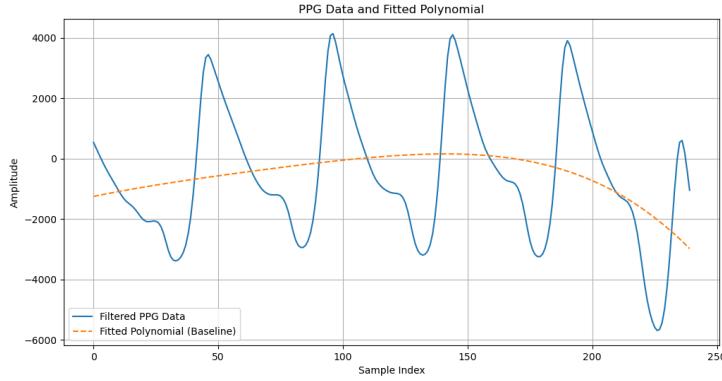


Figure 4: Polynomial fit to data sample

Finally, data is normalized. The full process makes our data more uniform, allowing for our CNN to focus on features that differentiate pulse.

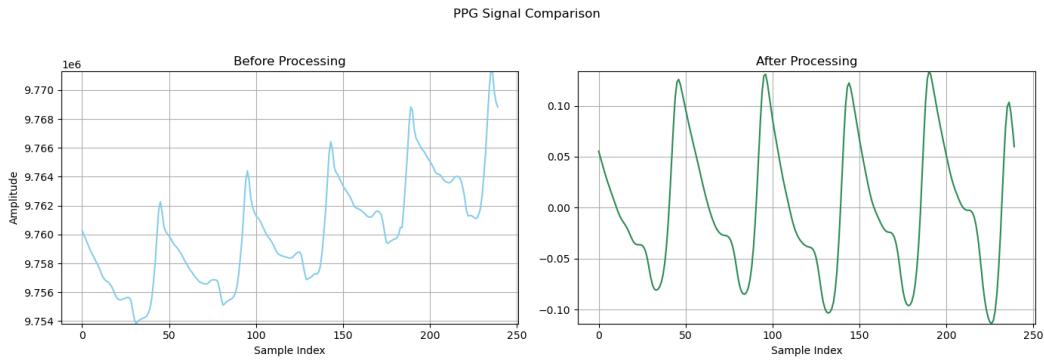


Figure 5: Before and after data preprocessing

Although this preprocessing can radically change data points, this results in clean data that performs well in our classification model.

Finally, when data is loaded for model training, it is shuffled randomly to mix up different sections of the dataset.

2 Model Structure

To classify four second signals into either a pulse or pulseless category, a 1D CNN was chosen. 1D CNNs are suitable for real time pulse detection because of their efficient feature extraction, resistance to noise, and potential for deployment on a compact architecture. These advantages come at the cost of needing a large, diverse dataset to avoid overfitting.

A typical 1D CNN structure was used, with convolutional layers followed by pooling layers followed by dense layers. A dropout layer was added to test the effectiveness of setting some inputs to zero. As seen in figure 6, the number of convolutional and max pooling layers is dependant on the hyperparameter N.

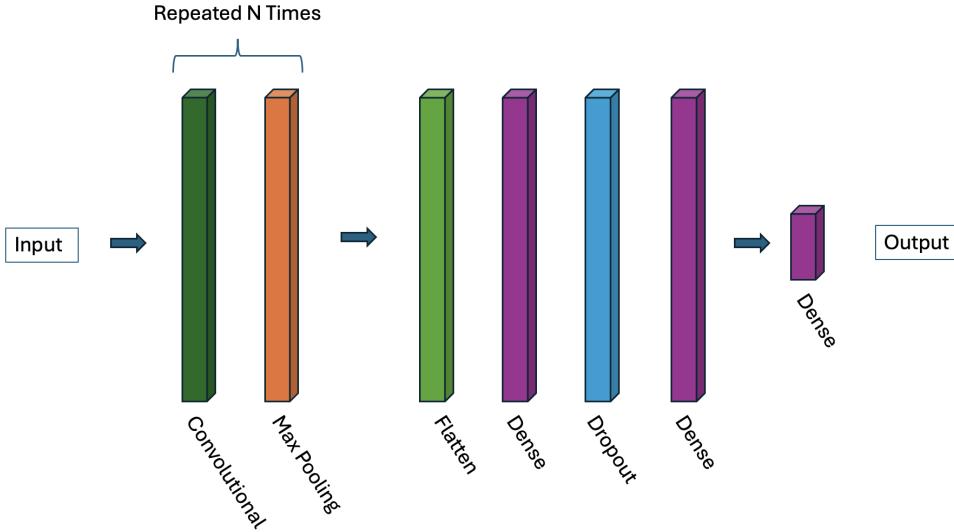


Figure 6: Structure of 1D CNN

3 Hyperparameter Sweeps

Four hyperparameters were targeted for sweeping, convolutional layers, dense points, dropout rate, and L2 rate. See the sections below for more details about these parameters.

When sweeping a parameter, the remaining parameters were set to the following values. These default values were established during preliminary sweeps.

Table 1: Default parameters

Parameter	Value
Convolutional Layers	3
Dense Points	128
Dropout Rate	0.2
L2 Rate	0.06

Sweeps were evaluated based on the accuracy of each model, as determined in the [TODO] section above.

3.1 Convolutional Layers

The number of convolutional layers is varied by adding N convolutional layers to the model, each followed by a max pooling layer (see figure 6). The number of filter of each subsequent convolutional layer is doubled, starting from 64 filters. This means that a model with N = 3 would have three convolutional layers with 64, 128, and 256 filters each.

The number of convolutional layers was swept from N = 1 to N = 6. The results of this sweep showed that having more layers was generally better. The best performing model used four layers for an accuracy of 95%.

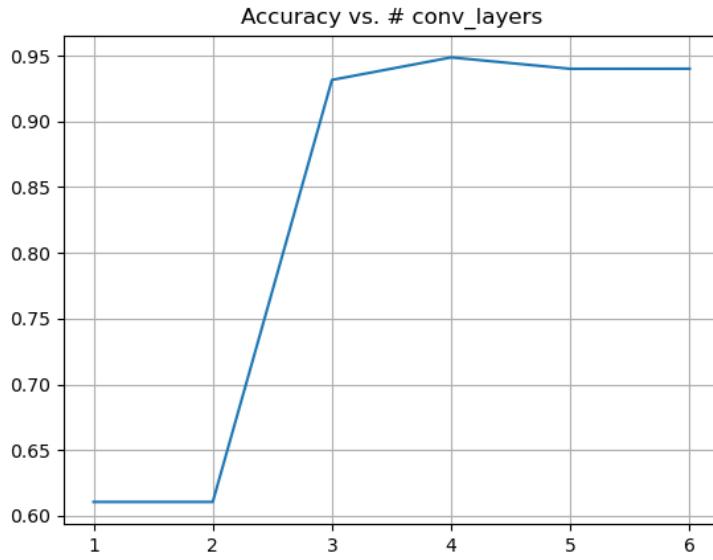


Figure 7: Convolutional Layers Sweep Results

3.2 Dense Points

The number of dense points in the first two dense layers was swept. A ratio of 2:1 was maintained between the first and second layer while the number of dense points was swept from 32 to 2042, incrementing in powers of two. This means when testing 256 points, the second dense layer has 256 points while the first has 512 points.

Surprisingly, the results of this sweep showed that having fewer dense points was generally better. This may be due to overfitting with more dense points. The best performing model used 32 and 64 dense points for an accuracy of 93%.

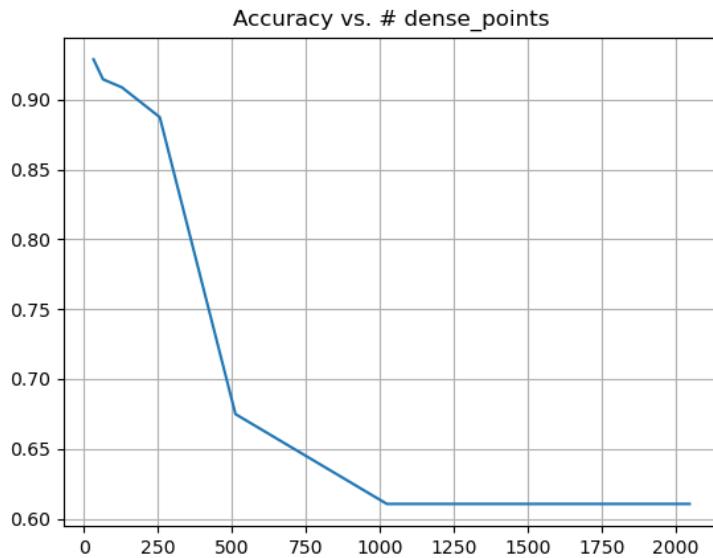


Figure 8: Dense Points Sweep Results

3.3 Dropout Rate

Dropout rate was varied in the dropout layer (see figure 6). The rate was varied from 0 to 0.5 with 0.01 increments. The results have little trend for this parameter, with small variance in accuracy compared to previous parameters. The best dropout rate was found to be 0.44, with an accuracy of 93%.

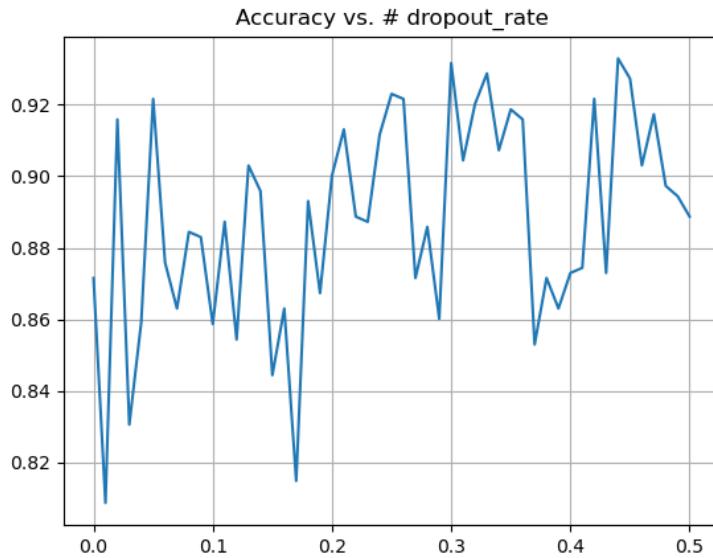


Figure 9: Dropout Rate Sweep Results

3.4 L2 Rate

L2 decay rate was used in the first two dropout layers. The rate was varied from 0 to 0.1 with increments of 0.005. It seems that a lower L2 rate leads to higher and more consistent accuracy. The best L2 rate was found to be 0.045, with an accuracy of 93%.

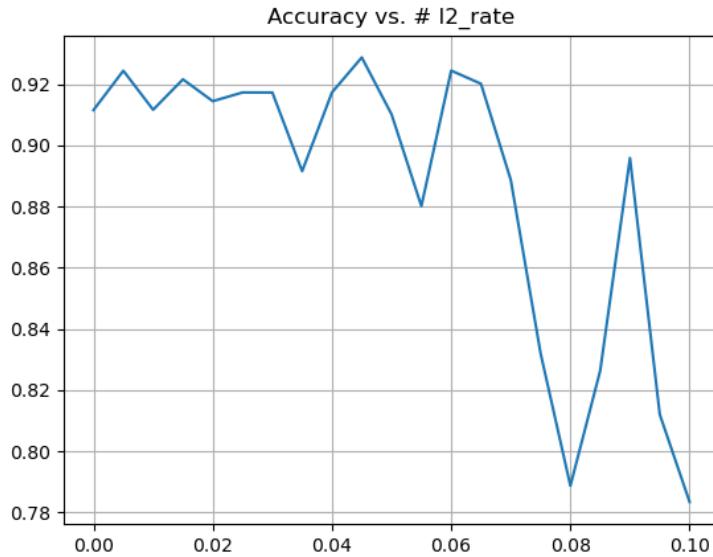


Figure 10: L2 Rate Sweep Results

4 Results

The hyperparameters as determined by the hyperparameter sweeps are shown in the table below.

Table 2: Optimal parameters

Parameter	Value
Convolutional Layers	4
Dense Points	32
Dropout Rate	0.44
L2 Rate	0.045

After training a model with these parameters, the final model has an accuracy of 96%. This exceeds any of the accuracies achieved on the parameter sweeps, indicating that this combination is effective.

Some examples of pulse data and the predictions of this model are displayed in the figures below.

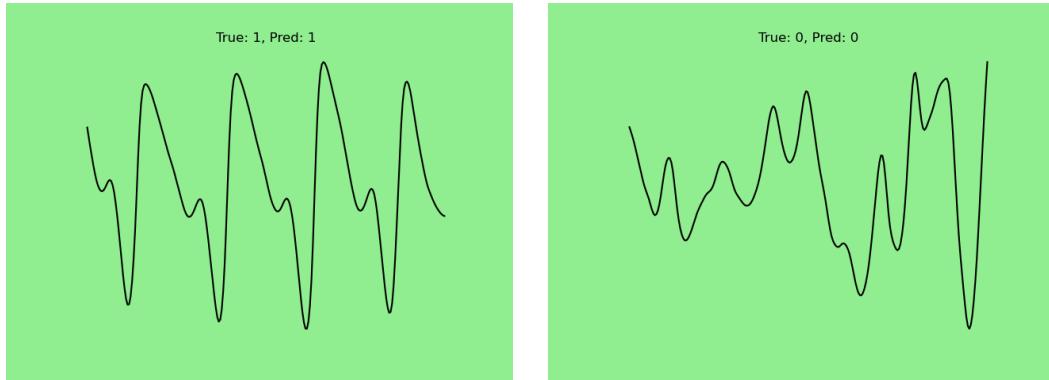


Figure 11: Correct predictions

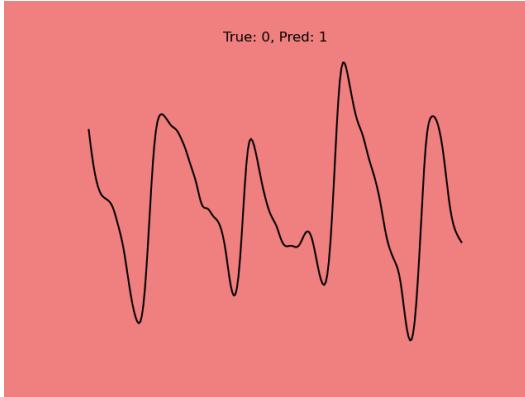


Figure 12: Incorrect prediction

As seen from figure 12, the data sample may actually have been labelled incorrectly, but identified correctly by this machine learning model. Many incorrect guesses seem to be on samples that from a human perspective may or may not have a pulse.

5 Discussion

These results seem extremely promising, with an accuracy that far exceeds many conventional pulse detection methods. This seems to be a suitable model to implement in a setting where real-time pulse detection is needed and limited data is available.

There are however some limitations that need to be investigated:

- This model is likely overfit, as the dataset it is trained on includes data from few people and at only a narrow range of possible heart rates. Training and testing this architecture on a larger, more diverse dataset would greatly improve its practical use.
- If the hyperparameters are interdependant, the hyperparameters could be further refined with more sweeps. Although gains may be incrementally smaller, this could likely improve the accuracy somewhat.
- Further hyperparameters may have an effect on the model and should be investigated. Optimization of this model still has a lot of potential, as only four parameters were investigated.

Despite these limitations, this model has yielded extremely impressive results, especially considering the small and somewhat imperfect dataset. There is much potential in using 1D CNNs for pulse detection.

6 Appendix

6.1 Appendix A

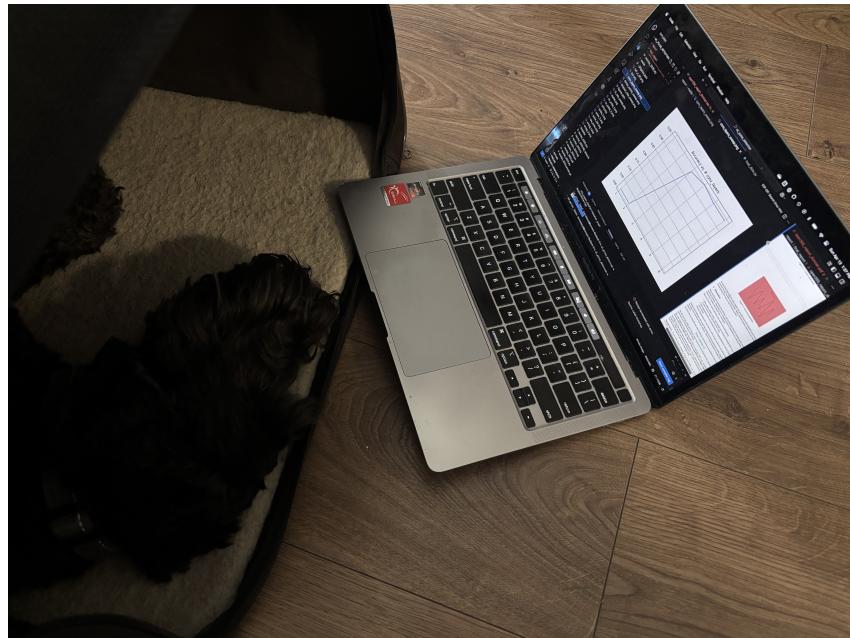


Figure 13: Co-author diligently reviewing results