Smart Sensor Calibration using Auto-Rotating Perceptrons

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Abstract

Sensor calibration is vital to have valid measurements of physical activities. Herein we deal with adjusting the signal from a wearable force sensor against a reference scale. By using a few samples and data augmentation, we trained a neural-based regression model to correct the wearable output. For this task, we tested the novel Auto-Rotating Perceptrons (ARP). We found that a neural **ARP model with sigmoid activations can outperform** an identical neural network based on classic perceptrons with **sigmoid and even ReLU** activation.

Background: What is an Auto-Rotating Perceptron (ARP)?

- The ARP, proposed by Saromo et al. [1], is an innovative neural unit that aims to avoid the vanishing gradient problem (VGP) by making the z inputs of the perceptron activation $\sigma(z)$ near zero with no learning alteration.
- The modification is achieved by multiplying the linear transformation $f(\mathbf{x})$ with an scalar coefficient ρ before the activation function $\sigma(z)$. ARP has two hyperparameters: $\mathbf{x}_Q = \langle x_Q, \cdots, x_Q \rangle \in \mathbb{R}^n$ and $L \in \mathbb{R}$.

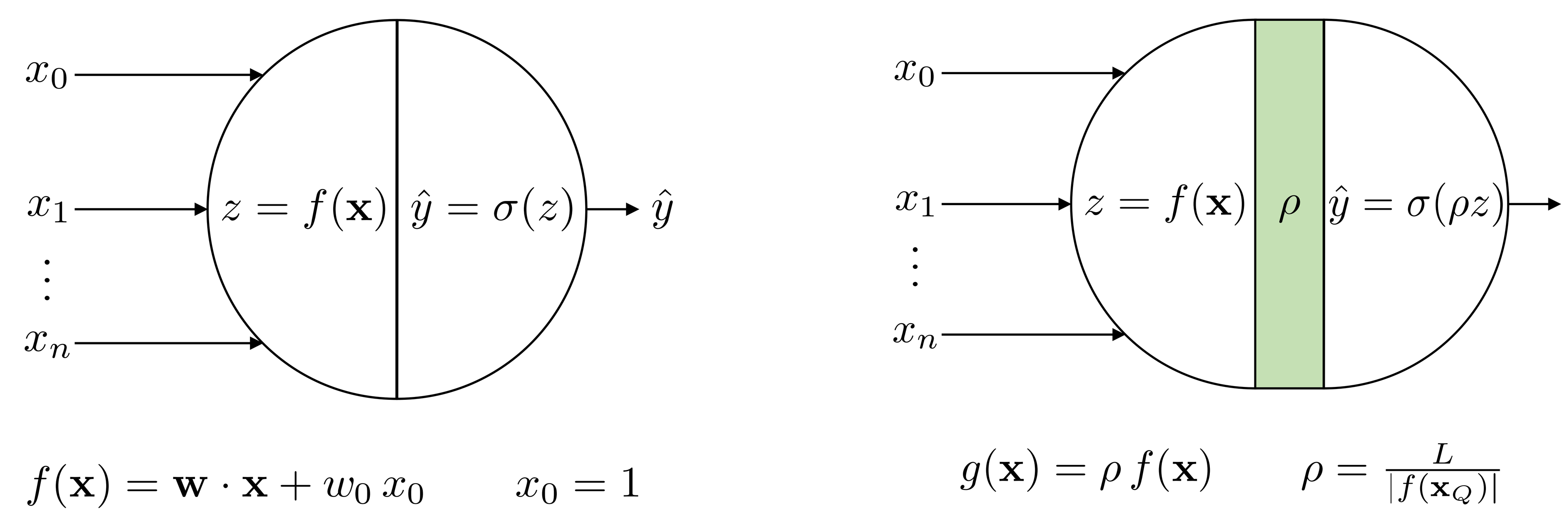

Figure 1: Classic perceptron (left) and ARP (right).

Problem definition

- We want to estimate the performance of an athlete by analyzing the internal loads generated during the movement. For this task, we built a **portable system** that measures Ground Reaction Forces (GRF).
- An insole-type WEarable VErtical Sensor system (WEVES) for GRF measurement was developed, see Figure 2.

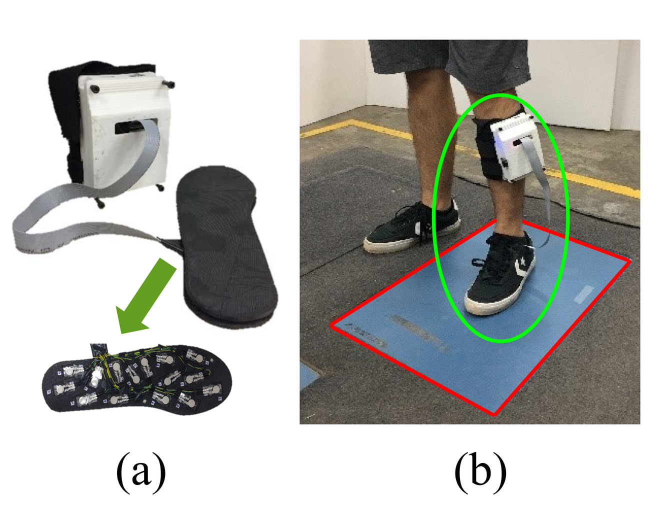

Figure 2: (a) WEVES with insole detail. (b) Stand-up straight position test with AMTI (red) and WEVES (green) sensors.

- WEVES measurement signal $\mathbf{w}$ must be as close to the AMTI platform signal $\mathbf{p}$ as possible.

Calibration requires scaling

- Due to the unknown internal dynamics of the WEVES insole, the GRF cannot be accurately measured.
- AMTI platform ($\mathbf{p}$) and WEVES ($\mathbf{w}$) signals are similar in shape, but there exists a difference in scale.

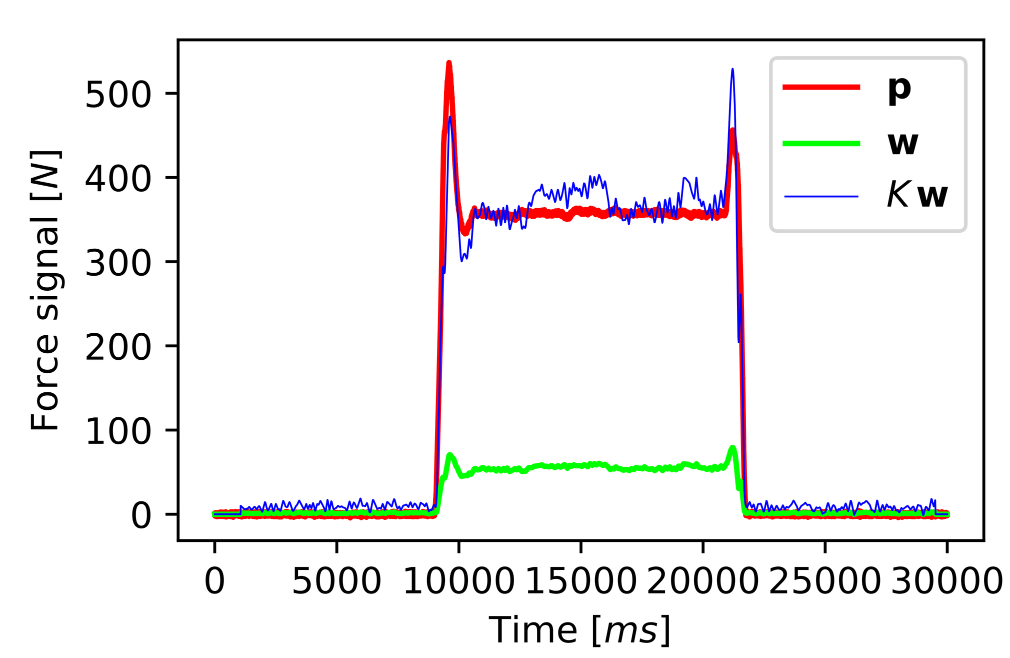

Figure 3: Force measurements (N): AMTI ($\mathbf{p}$, red), uncalibrated WEVES ($\mathbf{w}$, green), and scaled WEVES ($K\mathbf{w}$, blue).

- When using WEVES in practice, only $\mathbf{w}$ will be available to find the calibration factor K.

Calculating the calibration factor K

1. **Dataset generation:** We measured the difference between $\mathbf{p}$ and scaled $\mathbf{w}$ using the RMSE. Then, finding K is posed as an optimization problem:

$$K = \arg\min_{K} \{\mathrm{RMSE}(\mathbf{p}, K\mathbf{w})\}, \; K > 0.$$

Figure 4: Searching the K values that make $\mathbf{p}$ and $K\mathbf{w}$ similar.

Optimizers tested to calculate K: ABC and PSO.

2. **Factor K prediction:** We trained neural regression models to predict the target K using only $\mathbf{w}$.

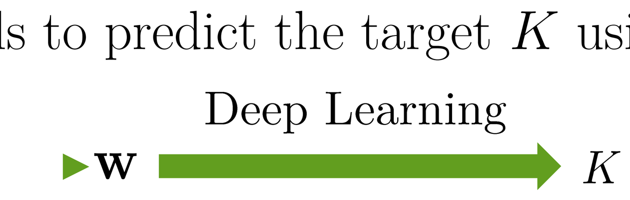

Figure 5: Inferring K from the WEVES signal $\mathbf{w}$.

We looked for reducing the loss prediction error of the regression. For this problem, we tested the effect of changing classic perceptrons to ARP, with two activation functions (sigmoid and ReLU).

Experimental results

- We compared four model types with the same architecture, but half of them had classic perceptrons, and the others used the novel ARP units. In both cases, we tested the sigmoid and ReLU activation functions.
- ARP hyperparameters used: $x_Q = 2.6$, since the maximum input value is $1 < x_Q$; and $L = 3$, because the unipolar sigmoid derivative $\sigma'(z)$ is not very small for $|z| \leq 3$.

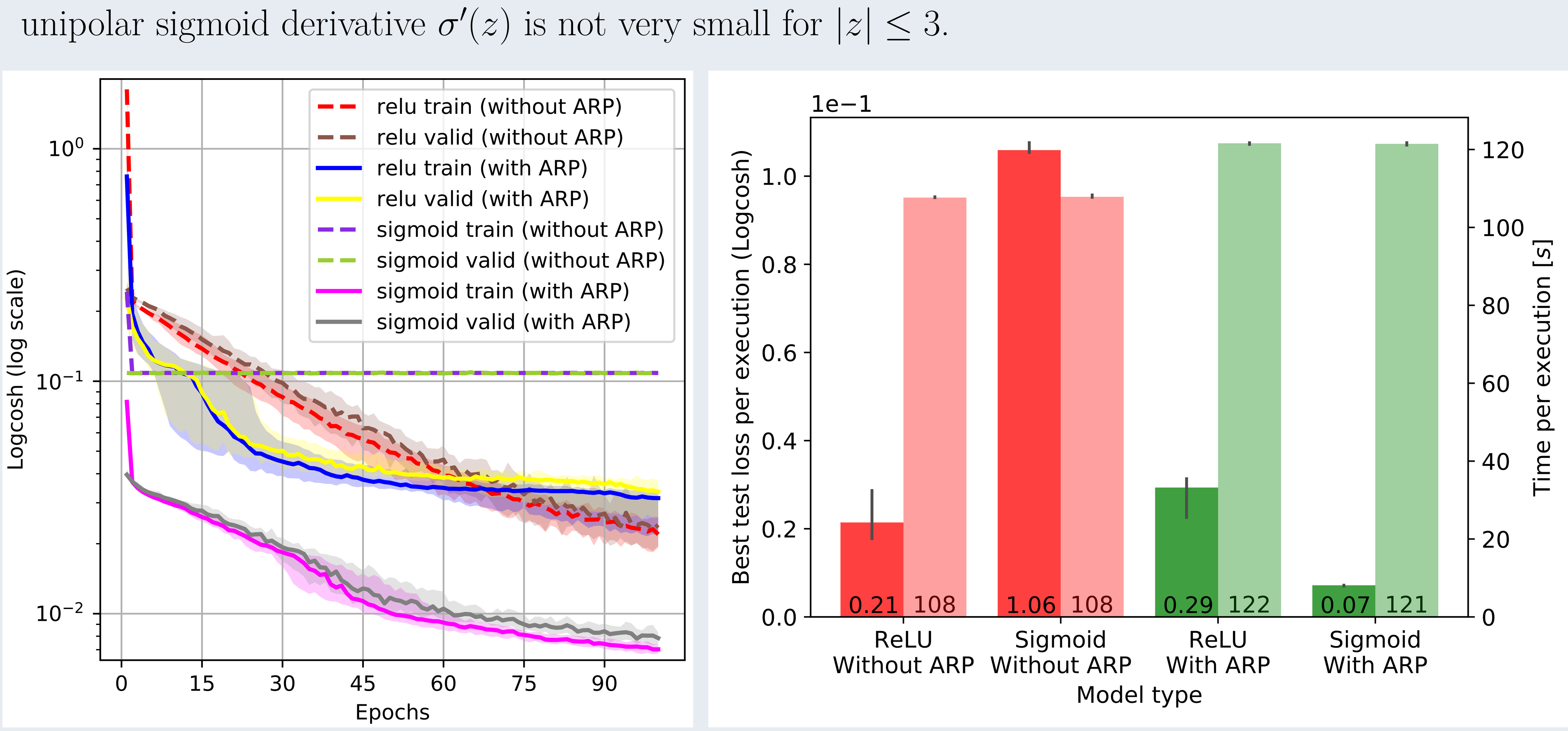

Figure 6: Comparison of the four model types tested. For each model family: 50 executions with 100 epochs per execution.

Insights

- We employed the ARP neural unit aiming to calibrate a wearable GRF sensor.
- ARP-sigmoid networks can have a better performance than ReLU networks with classic neurons.
- Compared with classic perceptrons that use sigmoid, the **test loss** of the sigmoid-ARP networks was **reduced by a factor of 15** at the cost of increasing the execution time by ~12%.

Acknowledgments

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References

[1] Saromo, D., Villota, E., Villanueva, E. "Auto-Rotating Perceptrons," *LatinX in AI Research Workshop at NeurIPS 2019*. Vancouver, Canada. 2019. arXiv: https://arxiv.org/abs/1910.02483.