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Bachelor's thesis

Gesture detector with Leap Motion sensor

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Declaration

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Abstrakt

V několika větách shrňte obsah a přínos této práce v českém jazyce.

Klíčová slova Replace with comma-separated list of keywords in Czech.

Abstract

Summarize the contents and contribution of your work in a few sentences in English language.

Keywords Replace with comma-separated list of keywords in English.

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Introduction

Mouse and keyboard are considered to be default devices for human-computer interaction nowadays. But with the maturity in technology, namely virtual and extended reality, the computer's need to understand human's body language is more and more present. Actions such as rotation or grabbing and moving an object in three-dimensional space with a computer mouse are unintuitive. They require a little understanding of the controls to execute the task. The movement is limited to the two-dimensional space of the mouse. Oppose to performing the desired action by hands in our three-dimensional space as we would in real life.

One of the proposed solutions for the issue is gesture recognition, where a general idea is for computers to have the ability to recognize gestures and perform actions base on them. Therefore, several devices were developed to process an image and yield useful data for gesture recognition. Some of them being Microsoft Kinect, a device where the main intention was to interpret whole-body movement, making it lacking in required accuracy for hand gesture recognition.

Another option would be using a Leap Motion Controller, developed specifically to track hand movements and extract its features, such as positions of fingers, hand rotation, and others. Its accuracy in finger detection is up to 0.01 mm.

Unfortunately, Leap Motion Controller has no official library for gesture recognition, limiting developers from utilizing the controller for its key features. Orion used to have a gesture detector with its 3.0 version, but the detector is absent with the release of more accurate version 4.0.

Chapter 1

Neural Networks

An artificial neural network (ANN) is a mathematical model mimicking biological neural networks, namely their ability to learn and correct errors from previous experience.[1][2]

The ANN subject was first introduced by Warren McCulloch and Walter Pitts in "A logical calculus of the ideas immanent in nervous activity" published in 1943.[3] But it was not until recent years when ANN has gained popularity with still increasing advancements in technology and availability of training data. ANN had become one of the default solutions for complex tasks which were previously thought be unsolvable by computers.[4]

This chapter will briefly explore different types of neural units and their activation functions, along with some exemplary network architectures.

1.1 Artificial Neuron

As previously mentioned, artificial neurons are units mimicking behaviors of biological neurons. Meaning it can receive as well as pass information between themselves.

1.1.1 Perceptron

Perceptron is the simplest class of artificial neurons developed by Frank Rosenblatt in 1958.[5]

Perceptron takes several binary inputs, vector $\vec{x} = (x_1, x_2, ..., x_n)$, and outputs a single binary number. To express the importance of respected input edges, perceptron uses real numbers called weights, assigned to each edge, vector $\vec{w} = (w_1, w_2, ..., w_n)$.

A step function calculates the perceptron's output. The function output is either 0 or 1 determined by whether its weighted sum $\alpha = \sum_i x_i w_i$ is less or greater than its threshold value, a real number, usually represented as an incoming edge with a negative weight -1.

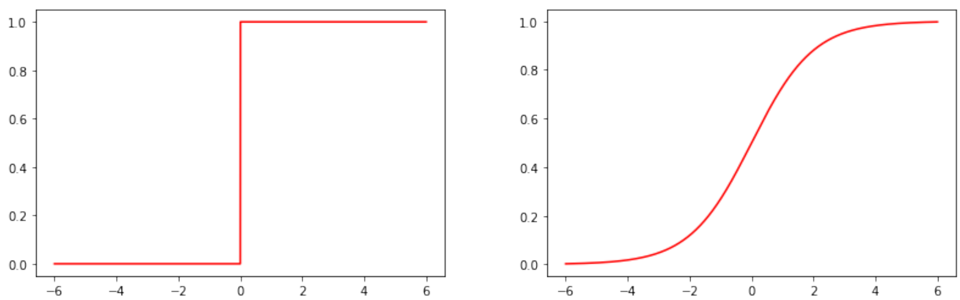
$$output = \begin{cases} 1, & \text{if } \alpha \geq threshold \\ 0, & \text{if } \alpha < threshold \end{cases} \tag{1.1}$$

PICTURE PERCEPTRON

1.1.2 Sigmoid Neuron

Sigmoid neuron, similarly to perceptron, has inputs $\vec{x}$ and weights. The key difference comes in once we inspect the output value and its calculation. Instead of perceptron's binary output 0 or 1, a sigmoid neuron outputs a real number between 0 and 1 using a sigmoid function.[6][7]

$$\sigma(\alpha) = \frac{1}{1 + e^{-\alpha}} \tag{1.2}$$



(a) Step function

(b) Sigmoid function

Figure 1.1: Comparison between step function and sigmoid function

As shown in Figure 1.1, the sigmoid function(1.1a) is a smoothed-out version of the step function(1.1b).

1.1.3 Activation Function

An artificial neuron's activation function defines that neuron's output value for given inputs, commonly being $f : \mathbb{R} \to \mathbb{R}$ [8]. A significant trait of many activation functions is their differentiability, allowing them to be used for Backpropagation, ANN algorithm for training weights. Having derivative not saturating or exploding, heads towards 0 or inf, is necessary for activation functions.

For such reasons, the usage of step function or any linear function is unsuitable for ANN.

1.1.3.1 Sigmoid Function

The sigmoid function is commonly used in ANN as an alternative to the step function. A popular choice of the sigmoid function is a logistic sigmoid. Its output value is in the range of 0 and 1.

$$\sigma(\alpha) = \frac{1}{1+e^{-\alpha}} = \frac{e^x}{1+e^x} \tag{1.3}$$

One of the reasons being the simplicity of derivative calculation:

$$\frac{d}{dx}\sigma(\alpha) = \frac{e^x}{(1+e^x)^2} = \sigma(x)(1-\sigma(x)) \tag{1.4}$$

One of its disadvantages being the vanishing gradient. A problem where for a given very high or very low input values, there would be almost no change in its prediction. Possibly resulting in training complications or performance issues.[9]

1.1.3.2 Hyperbolic Tangent

Hyperbolic tangent is similar to logistic sigmoid function with a key difference in its output, ranging between -1 and 1.

$$tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \tag{1.5}$$

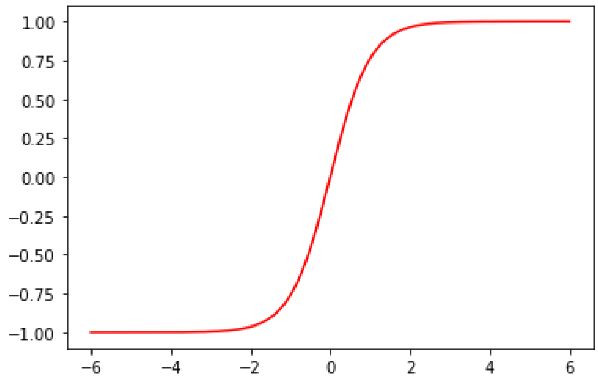


Figure 1.2: Hyperbolic tangent

It shares sigmoid's simple calculation of its derivative.

$$\frac{d}{dx}tanh(x) = 1 - \frac{(e^x - e^{-x})^2}{(e^x + e^{-x})^2} = 1 - tanh^2(x) \tag{1.6}$$

By being only moved and scaled version of the sigmoid function, hyperbolic tangent does share sigmoid's advantages and its disadvantages.[8]

1.1.3.3 Rectified Linear Unit

The output of the rectified linear unit (ReLU) is defined as:

$$f(x) = max(0, x) \begin{cases} x, & \text{if } x \geq 0 \\ 0, & \text{if } x < 0 \end{cases} \tag{1.7}$$

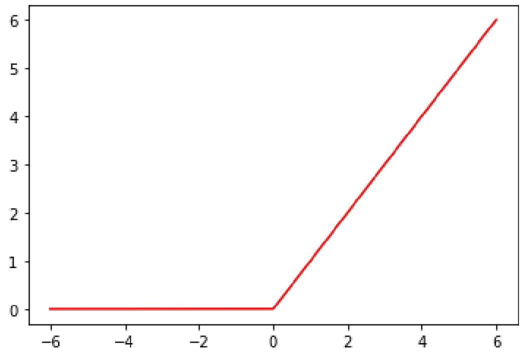


Figure 1.3: Rectified Linear Unit

ReLU popularity is mainly for its computational efficiency.[9] ReLu's disadvantages appear when inputs approach zero or are negative. Causing the so-called dying ReLu problem, where the network is unable to learn. There are many variations of ReLu to this date, e.g., Leaky ReLU, Parametric ReLU, ELU, ...

1.1.3.4 Softmax

Softmax separates itself from all the previously mentioned functions by its ability to handle multiple input values in the form of a vector $\vec{x} = (x_1, x_2, ..., x_n)$ and output for each x_i defined as:

$$\sigma(x_i) = \frac{e_i^x}{\sum_{j=1}^{n} e_j^x} \tag{1.8}$$

For output being normalized probability distribution, ensuring $\sum_i \sigma(x_i) = 1$.[10] It is being used as the last activation function of ANN to normalize the network's output into n probability groups.

1.2 Types of Neural Networks

To this day, there are many types and variations of ANN, each with its structure and use cases. Here we will briefly introduce the most common ones, such as feed-forward networks, convolutional neural networks, or recurrent neural networks.

1.2.1 Feed-forward Networks

Feed-forward network (FNN) first ANN to be invented and also the simplest form of ANN. Its name comes from how the information flows through the network. Its data travels in one direction, oriented from the input layer to the output layer, without cycles.[11] FNN may or may not contain several hidden layers of various widths. By having no back-loops, FNN generally minimizes error in its prediction by using the backpropagation algorithm to update its weight values.[12]

GRAPH

The input layer takes input data, vector $\vec{x}$, producing $\hat{y}$ at the output layer. The process of training weights consists of minimizing the loss function $\mathcal{L}(\hat{y}, y)$, y being the target output of input $\vec{x}$.[10]

1.2.1.1 Backpropagation

Backpropagation, short of backward propagation of errors, is a widely used algorithm in training FFN using gradient descent to update the weights. [13]

$$\vec{w}_{i+1} \leftarrow \vec{w}_i - \gamma \nabla F(\vec{w}_i) \tag{1.9}$$

Its generalization is used for other ANNs, providing a way to calculate the gradient backward through the network. A gradient of the final layer of weights being calculated first, and the gradient of the first layer being calculated last. [13] real number value expressing prediction incorrectness.[14]

1.2.2 Convolutional Neural Networks

Convolutional Neural networks (CNN) primary goal is to make a computer recognize images and objects. For such, it is primarily used for image classification or object recognition.

CNN was inspired by the biological processes of the human brain. Its connectivity patterns resemble the human's visual cortex. But an image is perceived differently by a human brain than by a computer. To a computer, an image is interpreted as an array of numbers. Thus CNN is designed to work with two-dimensional image arrays, although it is possible to work with one-dimensional or three-dimensional arrays too.[15]

CNN is a variation of FNN.[14]. It usually consists of the input layer followed by multiple hidden layers, typically several convolutional layers with standard pooling layers, and ending with the output layer.

1.2.2.1 Convolutional Layer

The convolutional layers' objective is to extract key features from the input image by passing a matrix known as a kernel over the input image abstracted into a matrix.[16]

IMAGE

The convolution result can be of two types depending on their size. One being the convolved feature is reduced in dimensions compared to the input, valid padding. For example, an input image of dimensions 8x8 being reduced to 6x6 after convolution operation. And the other type being where dimensions are either increased or remain the same, same padding. [17]

1.2.2.2 Pooling Layer

Similar to the previously mentioned convolutional layer, the pooling layer reduces the convolved feature's spatial size to decrease the computational power required for data processing. Furthermore, being useful by extracting dominant features, which are rotational and positional invariant, thus maintaining the process of effectively training the model.[17]

There are two types of pooling: max pooling and average pooling. Max Pooling returns the maximum value from the portion of the image covered by the kernel.It performs as a noise suppressant, discarding the noisy activations altogether and performing de-noising and dimensionality reduction. Where average pooling returns the average of all the values from the same covered portion, performing dimensionality reduction as a noise suppressing mechanism. Hence, it is possible to note that max-pooling performs better.[17]

IMAGE

1.2.3 Recurrent Neural Networks

Recurrent Neural Network (RNN) is distinguished by its memory, taking input sequence with no predetermined size. Its past predictions influence currently generated output. Thus for the same input, RNN could produce different results depending on previous inputs in the sequence.[18].

RNNs features make it commonly used in fields such as speech recognition, image captioning, natural language processing, or language translation. Some of the popular being, for example, Siri, Google Translate or Google Voice search.[19]

As previously mentioned, RNN takes into consideration information from previous inputs. Let us look at the idiom ”feeling under the weather”, where for it to make sense, words have to be in a specific order. RNN needs to account for each word's positions and use its information to predict the next word in the sequence. Each time step represents a single word. In our case, the third timestep represents ”the”. Its hidden state holds information of previous inputs, ”feeling” and ”under”.[19]

SCHEMATIC

Figure XX shows the network for each time step, i.e., at time t, the input $\vec{x_t}$ goes into the network to produce output $\hat{y}_t$, the next time step of the input is x_{t+1} with additional input from the previous time step from the hidden state h_t. This way, the neural network looks at the current input and has the context from the previous inputs. With this structure, recurrent units hold the past values, referred to as memory. Making it possible to work with a context in data. [20]

The recurrent unit is calculated as follows:

$$h_t = f(W_x x_t + W_h h_{t-1} + \vec{b_h}) \tag{1.10}$$

$f()$ being the activation function, W_x, W_h are weight matrixes, x_t is the input, and $\vec{b_h}$ is the vector of bias parameters. Unit at time step $t = 0$ is initialized to $(0, 0, ..., 0)$. The output $\hat{y_t}$ is then calculated as:

$$\hat{y_t} = g(W_y h_t + \vec{b_y}) \tag{1.11}$$

$g()$ also being an activation function, usually being softmax to ensure the output is in the desired class range. W_y is the weight matrix and $\vec{b_y}$ being a vector of biases determined during the learning process.

Training RNNs uses a modified version of the backpropagation algorithm called backpropagation through time (BPTT), working by unrolling the RNN [14], calculating the losses across time steps, then updating the weights with the backpropagation algorithm. More on RNN in [10] by Liton et al.

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Appendix A

Acronyms

GUI Graphical user interface

XML Extensible markup language

Appendix **B**

Contents of enclosed CD

```
readme.txt ........ the file with CD contents description
exe ............... the directory with executables
src ............... the directory of source codes
  wbdcm ........... implementation sources
  thesis .......... the directory of LaTeX source codes of the thesis
text .............. the thesis text directory
  thesis.pdf ...... the thesis text in PDF format
  thesis.ps ....... the thesis text in PS format
```