Human-posture-tracking sensor selection for motion recognition

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Abstract: Very recently special attention has been paid to soft sensors for motion tracking. It is known from the work by Chen et al [2021, Comp Anim Virtual Worlds. 2021; e1993.] that a wearable motion tracking system was developed, in which five sensors were placed around the region of arm and shoulder. In this study, we explore the effect of different sensors on motion recognition and select the sensors with excellent differentiation for different movements.

1. Introduction
Using sensors to capture motion or action is a very important cutting-edge technology in the field of VR or animation [1], especially focusing on flexible sensors. Previous studies focused on the comprehensive effects of all parts (palms, arms, shoulders, and fingers [2]) on motion recognition, while our research focused on the selection of the part which has a higher degree of discrimination for distinguishing different actions.

The movement of the arm mainly depends on the change of the elbow and shoulder joints. In [3], Chen et al developed a wearable garment with some flexible sensors, three of which are on the shoulders and the last one is on the elbows. They tracked the rotation of the joint by monitoring the change in the resistance of the stretchable sensor. For example, when the user bends the elbow joint, the sensor is stretched, and its resistance value increases accordingly. Inspired by this work, here we are interested in which sensor would have better performance for movement (pattern) recognition. We mainly tested two patterns, one is to rotate the arm around the body in a circle, and the other is to raise the arm and then fall vertically to form a semicircle. Besides, we chose to use two distances, Euclidean distance and cosine distance to measure the degree of discrimination between different sensors., and use Principal Component Analysis dimensionality (PCA) reduction to visualize the discrimination ability.

We summarize our key findings as below:
- Compared with cosine distance, Euclidean distance is a more discriminative measure;
- The result of Euclidean distance and the result of PCA dimensionality reduction show a relatively strong association;
- The Euclidean distance of sensor 2 and the results of PCA both show that the two patterns have a high degree of discrimination.
2. Data Specification

2.1 Data Sources
We use the dataset in [3]. The data were collected from a man whose age is 28. He did 7 different patterns of actions according to his preferences. He kept repeating these actions so that one could collect enough data. The collection was about 1.5 hours each time, including the time to rest if he got tired.

2.2 Sensors
The sensor is sewn on the clothes by hand using flat stitch technology. There are four sensors, three around the shoulder joint and the last one at the elbow joint.

![Figure 1. Pattern 1 and the data collected by Sensor 1](image)

3. Data analysis

3.1 Data preprocessing
I drew the data of different groups at the same sensor into a line graph and observe the trend. I mainly completed Pattern 1 and Pattern 2. I found that these data are not the same in length, some are long and some are short, but there are no outliers. Therefore, I simply cut the data so that all groups of data have the same length. It is shown that this preprocessing does not affect the data analysis.

3.2 Calculating distance

![Figure 2. Different data from Sensor 1](image)
I calculated the distance between the two patterns at different sensors, using the cosine distance and the Euclidean distance.

Euclidean distance: In mathematics, the Euclidean distance between two points in Euclidean space is the length of a line segment between the two points. Its formula is:

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$  \hspace{1cm} (1)$$

Cosine distance (Cosine similarity) is a measure of similarity between two non-zero vectors of an inner product space. It is defined to equal the cosine of the angle between them, which is also the same
as the inner product of the same vectors normalized to both have length 1. The cosine of 0° is 1, and it is less than 1 for any angle in the interval (0, π] radians. It is thus a judgment of orientation and not magnitude: two vectors with the same orientation have a cosine similarity of 1, two vectors oriented at 90° relative to each other have a similarity of 0, and two vectors diametrically opposed have a similarity of -1, independent of their magnitude. Its formula is:

\[
\sin(x, y) = \cos \theta = \frac{\vec{x} \cdot \vec{y}}{||\vec{x}|| \cdot ||\vec{y}||}
\]

Euclidean distance reflects the absolute difference in value, while cosine distance reflects the relative difference in direction.

**Table 1. Calculations of two distances**

| Pattern 1  | Pattern 2  | Pattern 3  | Pattern 4  |
|------------|------------|------------|------------|
| Euclidean distance | 259.7172 | 1342.576 | 968.3688 | 1801.898 |
| Cosine distance | 0.999982 | 0.997053 | 0.994095 | 0.995003 |

By taking a look at the mean plots of four patterns, we can see that the cosine distances are very close, so there is no discrimination. It reminds us that it is more convincing to use Euclidean distance to distinguish.

### 3.3 Principal Component Analysis (PCA)

In the real coordinate space, the principal component [4] of the point set is a sequence of p unit vectors, where the i-th vector is the direction of the straight line orthogonal to the i-1th vector and most suitable for the data. Here, the best fit line is defined as the line that minimizes the average square distance from the point to the straight line. These directions form an orthonormal basis, in which the different dimensions of the data are linearly uncorrelated. Principal component analysis (PCA) is the process of calculating principal components and using them to make fundamental changes to the data. Sometimes only the first few principal components are used and the rest are ignored for exploratory data analysis and prediction models. It is usually used for dimensionality reduction. The method is to project each data point only on the first few principal components to obtain low-dimensional data while keeping the data changes as much as possible. The first principal component can be equivalently defined as the direction that maximizes the variance of the projection data. The i-th principal component can be used as a direction orthogonal to the i-1th principal component to maximize the variance of the projection data.
4. Conclusions
By comparing the two distances (cosine distance versus Euclidean distance), the discrimination of cosine distance is not as good as the discrimination of Euclidean distance. One possible explanation is that the cosine distance characterizes whether the trends of the two vectors are consistent, while the Euclidean distance pays more attention to the absolute value of the signal. Thus, in this study, we found
that the absolute value of the signal is a more important evaluation criterion than the trend.

In future plan, we will improve our work in the following two directions. One is that we only studied two of the seven patterns (movements) in this work. Different conclusions may appear during the comparison of other patterns. Specifically, the performance of different distances may differ in other patterns. The second is we will use more comprehensive data preprocessing methods than this study. Here we simply align the vectors (remove the redundant components), there are some other ways to align different vectors by shrinking or amplifying the signals.

References
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