A Metric for Hand Comfort/Discomford Evaluation

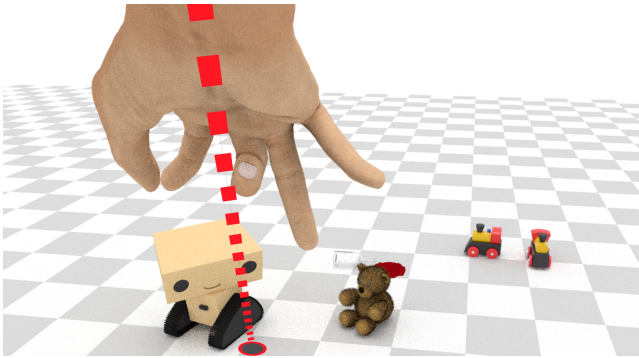## Towards Expressivity in Spatial Control

Figure 1: Controlling a Robot using Hand Postures

ABSTRACT

In this paper a straightforward metric for quick comfort and discomfort evaluation of non-resting hand postures is proposed, which is improved using data from user studies. Comparing user ratings with the metric indicates the metric to be a fitting extrapolating model for perceived comfort and discomfort. Our results also indicate the affect of hand comfort and discomfort on precision and performance.

CCS Concepts

•**Human-centered computing → Interaction design theory, concepts and paradigms;**

Keywords

comfort/discomfort metric, hand posture

1. INTRODUCTION

For a traditional desktop computer environment, there exist a number of different standardized interfaces for human-computer interaction using a mouse, keyboard and monitor, that allow the user to complete a variety of tasks effectively and efficiently by providing sets of shortcuts and macros.

However, in contexts such as virtual reality and robotics traditional input methods are often not suitable for the tasks environment. Therefore both speech as well as hand gestures and postures are common concepts. While speech interaction is often struggling with its limited powerfulness for spatial navigation, the latter is trivial for gestures and postures (Figure 1). The main challenge for gestures and postures has been fighting physical forces that cause fatigue or discomfort and therefore limiting user experience as well as precision and performance as indicated by Short et al. [4]. Even though comfort and discomfort are often taken into consideration by designers, there still only exist very few quantitative methods for their evaluation[3].

This work is meant to support the creation and evaluation of a hand posture catalog for effective and efficient human-robot interaction by proposing a hand posture comfort/discomfort metric, that allows for quick objective hand posture evaluation. State of the art comfort/discomfort models were applied to current hand anatomy and ergonomics knowledge to create models for hand comfort and discomfort. Based on our model we created a naive metric, that we improved in a second step using data from a user study. Finally another user study was used to validate our metric and to show the impact of comfort and discomfort on performance in a pointing task.

We will first explain the theoretical basis of our comfort/discomfort model, before deriving our naive metric from it. After that we will explain the methodology used for optimizing and validating the metric as well as for showing the relevance in the example of target shooting. Finally, the results will be analyzed and discussed, before evaluating and putting our findings in a greater context.

2. HAND POSTURE COMFORT/DISCOMFORT METRIC

The structure of the metric proposed is based on current ergonomics models, defining comfort as a "pleasant state or relaxed feeling of a human being" mostly caused by subjective impressions and expectations and discomfort as "an unpleasant state of the human body" occurring from physical stress[6]. Using this information and knowledge of the human hand anatomy, we broke down human hand comfort and discomfort in a non-resting hand into the following four components, that will be explained in the following sections:

- Deviation from Range of Rest Posture (RRP)
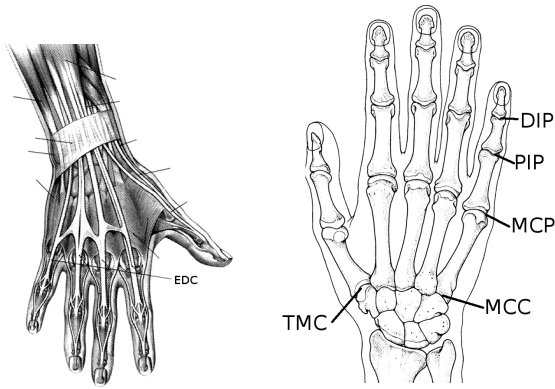
- Inter Finger Angles (IFA)

Figure 2: Hand anatomy

- Finger Hyperextension (HE)

- Finger Abduction (FA)

For the computation of our metric we used an angle based hand model, similar to the model described by Su et al. [5], as it makes reading joint angles pretty trivial. Instead of the full 23 degrees of freedom, described by LaViola [2], we used a simplified model that neglects the MCC (metacarpocarpal joint) (Figure 2) of the fourth and fifth digit. The simplification was applied because of the **Leap** using the same model for detecting hands and due to the MCC not being noticeable to influence hand postures at all.

The 21 DOF angle based hand model was futhermore simply handled as a vector of 21 `float`s.

2.1 Deviation from Range of Rest Posture

Range of Rest Posture (RRP) is a range of angles for an articular joint[1], where the joint "can be considered statistically in rest", caused by muscle relaxation and therefore creating a maximum of comfort in this particular joint[1]. In our case, we considered the human hand to have a RRP for each finger joint in a non-resting position with the palm facing downwards, resulting in a range of relaxed hand postures where the comfort is maximized.

For articular joints perceived comfort decreases when deviating from the RRP. It minimizes at the bounds of the natural range of motion. Applying this to the whole hand leads to the conclusion, that hand posture comfort can be evaluated by adding up the individual joint angle distances to the RRP. [3]

In our implementation the RRP was represented by a set of 50 relaxed hand postures recorded with the Leap. The metric **RRP(x)** was simply computed by calculating the minimum euclidean distance of a Hand denoted as "x" to the RRP set. For simplicity we supposed the comfort to linearly decrease with distance to the RRP in our metric.

2.2 The Inter Finger Angles

As it can be seen in Figure 2 the hand has a very compact and highly connected system of muscles and tendons that limits the individual movement of fingers. The fingers, excluding the thumb, share *most* of their flexor and extendor muscles, however minor individual flexion and extension of

---

[1]The word "articular joint" refers to the joints in the human body.

adjacent fingers is still possible due to finger tendons originating from different areas of the muscles. In the case of the EDC (*Extensor digitorum communis*) (Figure 2) the finger tendons are even interconnected on the back of the hand.

Therefore hand postures with high bending differences of adjacent fingers, excluding the thumb, should lead to stress of tendons and muscles, as well as cognitive stress, minimizing comfort and increasing perceived discomfort.

The **inter finger angle component IFA(x)** was computed by first summing up the flexion/extension angles of MCP (*metacarpophalangeal*), PIP(*proximal interphalangeal*) and DIP (*distal interphalangeal*) joints (Figure 2) for each finger and adding up the differences in total bending of adjacent fingers (3 values). In order to compensate anatomical differences of the fingers, mostly affecting the ring finger, we added a ring finger bonus consisting of the difference of the ring finger's bending to both of his neighbors multiplied with an estimated weighting coefficient. The importance of this differentiation can be seen in when extending the index finger from a closed fist as opposed to extending the ring finger.

2.3 Finger Hyperextension

Hyperextension (Figure 3) *"puts more strain on the [MCP] joints and tendons than the hand is accustomed to"* [2] and therefore causes discomfort [2]. Even though this might seem redundant to the deviation from RRP on first sight, hyperextension takes a special position as it causes considerably more discomfort, compared to a full flexion of the fingers and compared to what the deviation from RRP would suggest.

For the **hyper extension** component **HE(x)** we simply summed up the the flexion/extension angle of the fingers MCP that had a negative angle and were therefore hyperextended.

2.4 Finger Abduction

Finger **abduction** (Figure 3) also causes stress on the MCP joint, the abduction muscles and tendons involved.

It was therefore also considered, analogue to the hyperextension, due to full abduction creating substantially more discomfort than full adduction.

We computed the **abduction** component **FA(x)** by adding up the absolute abduction/adduction angle for the finger, based on the knowledge, that in our model a fully adducted finger has an abduction angle of 0.

2.5 Naive Metric

Based on the model mentioned above[6], we then assigned the components to either comfort or discomfort. We then designed our metrics to be the added up component values $(RRP, IFA, ...)$ multiplied with weighting coefficients
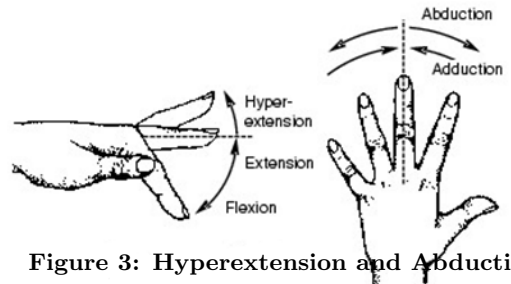

Figure 3: Hyperextension and Abduction

$(c_{RRP(x)}, c_{IFA(x)}, ...)$. These weighting coeffitients were estimated for the **naive metric.**

$$Comfort(x) = c_{RRP} \cdot RRP(x)$$

$$Discomfort(x) = c_{IFA} \cdot IFA(x) + c_{HE} \cdot HE(x) + c_{FA} \cdot FA(x)$$

The resulting metrics are expected to correlate with user perception, having the value 0 as maximum comfort and minimum discomfort respectively.

2.6 Improved Metric

Even though the naive metrics contain the causes for comfort and discomfort, they still lack deeper consideration for the anatomical differences between the fingers. The concept of improvement extends the thought process already used for inter finger angles: instead of applying the metrics to the whole hand, have a look at the contributions from the individual fingers and weight them with importance coefficients.

$$Discomfort = c_{IFAindex} \cdot IFA(index) + c_{IFAmiddle} \cdot ...$$

In our case we have 5 comfort values and a total of 12 discomfort values.

However, the exact weighting coefficients are generally unknown and hard to estimate. To solve this problem, we reduced it to a curve fitting problem with 17 unknowns and used data, obtained from user evaluations to find the correct coefficients.

3. METHODOLOGY

For the collection of data, we created a test environment using **Unity 3D** with a total of two tasks. In the fist task, the subject would be shown a randomly generated hand posture on screen, using our naive metric to ensure a somehow homogenous distribution of expected comfort and discomfort. The subject was asked to mimic the hand posture with his or her dominant hand and afterwards rate the hand. As we did not expect the subjects to be familiar with current comfort and discomfort models, we asked them to rate hand postures on intuitive scale ranging from 10 (very comfortable) to 0 (very uncomfortable). The subject was told to rate the hand posture with 0 points if he or she was unable to reproduce it. Before the actual evaluation subjects were shown two hand postures as a point of reference for comfort and discomfort. The first hand posture was a completely relaxed hand, the second hand posture was a randomly generated hand, that was challenging to mimic (Figure 1).

In the second task, the subjects was again given a randomly generated hand posture. Again the subject had to mimic the hand posture with his dominant hand and give it a rating from 0 to 10. After confirming his or her rating, the subject had to perform a target shooting task (Figure 4). Therefore we tracked the back of the subject's hand using an **ART Hand Tracking Device**, giving the subject a minimalistic representation of their hand position and indicating the forward direction of their hand with a rendered ray. The seated subject, with the elbow rested on a table, had to use this ray to aim down a total of 12 targets, appearing in random order, and shoot them, by pressing a button with the off-hand. By recording the hand posture before the trial using a Leap, and checking the hand posture during the test, we made sure that the user would not break the posture.
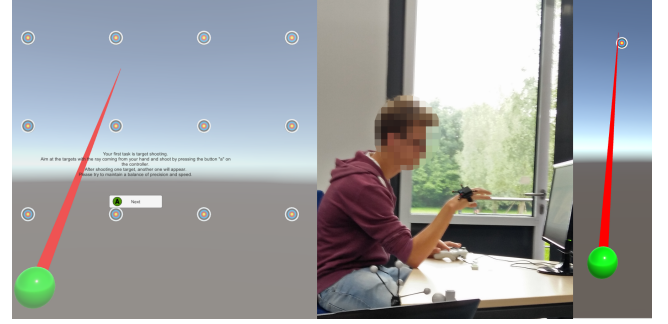

Figure 4: A Participant performing the Target Shooting (best in Colour)

As a metric for performance, we measured the total time taken for the test. In order to have this affected by precision, we made the targets rather small and told the subjects to perform the test as quickly as possible.

We conducted a total of two user studies involving 21 voluntary participants, that gained us 250 and 60 data sets for the metric and one study gaining us 35 data sets for the target shooting. The subjects were informed about the aim of the study as well as their specific objectives beforehand.

As we expected both comfort and discomfort to affect performance and due to the users only giving us one value for comfort and discomfort, we decided to combine comfort and discomfort in our model as well. Finding the best fitting coefficients can be reduced to a curve fitting problem. Therefore we used the least squares algorithm on the first 250 data sets to fit the comfort/discomfort values to the user ratings. Afterward we tested our results against the remaining 60 data sets to check them for correctness.

4. RESULTS & DISCUSSION

Unsurprisingly, there was a correlation in the training data between the user rating and our improved metric generated with this data (Figure 5). However, the correlation found is still not perfect having a value of approx. *-0,65* (Table 1). For this we suspect multiple reasons:

The participants most likely had differences in anatomy and set of mind, witch caused them, to subjectively rate comparable postures differently. In addition to that subjects had to give their rating after a relative short amount of time, therefore long time discomfort symptoms, like pain or cramping, might not have been experienced. Finally, the users could only rate the hands of continuous comfort/discomfort on a scale with 11 discrete steps, which probably created some additional error.

Even though the metric was created using a limited set of training data, it yielded a comparable correlation when applied to the test data (Figure 6). This indicates that the improved metric is a decent extrapolation of the training data. Compared to the naive metric(Figure 7), there is only mi-

#Figure	Correlation	p-value
5	-0.6453242	< 2.2e-16
6	-0.748993	5.89e-12
7	-0.6651999	6.73e-9
8	0.4236101	0.01122

Table 1: Pearson Correlations and P-values

nor difference on first sight. However, the improved metric reduced the standard error, resulting in a better correlation and p-value.

The results from the target shooting task (Figure 8) indicate, that comfort and discomfort, as measured by our metric, do affect the performance and precision in context of hand postures. This strengthens the conclusion of Short et al. [4], that more comfortable postures generally create greater accuracy. However, the credibility of our results is limited by the relatively small dimensions of the user studies and more work and research will have to be done, in order to make strong conclusions.

Even though the results of this paper only apply to hand posture comfort/discomfort, the process of creating and testing a comfort/discomfort metric and its influence on performance/precision, as shown in this paper, can be transferred to other parts of the body.

5. CONCLUSION & FUTURE WORK

The main goal of this paper was to create a metric for quick and objective evaluation of hand posture comfort and discomfort and to demonstrate its relevance for design of hand postures, by proving its influence on precision and performance in a 3D pointing task. For the creation of the metrics we applied knowledge of the hand's anatomy and state of the art comfort and discomfort models and used data from a user study to optimize the metric. Results from the testing user study suggest the improved metric to be a valid inference of the training data. In addition the outcome of a small target shooting test indicate the existence of a correlation between comfort/discomfort and precision/performance, as already suggested for other contexts in other papers.

An important next step would be to take into account factors, neglected in this paper, for example long term effect of a hand posture on the perceived comfort and discomfort as well as on the performance and precision. Furthermore it would be helpful to determine other factors that might influence performance of a single hand task, to be able to find an optimum set of hand postures.

6. REFERENCES

[1] A. Apostolico, N. Cappetti, C. DâĂŹOria, A. Naddeo, and M. Sestri. Postural comfort evaluation: experimental identification of range of rest posture for human articular joints. *International Journal on*

Interactive Design and Manufacturing (IJIDeM), 8(2):109–120, 2014.

[2] J. LaViola. A survey of hand posture and gesture recognition techniques and technology. *Brown University, Providence, RI*, 29, 1999.

[3] A. Naddeo, N. Cappetti, and C. D'Oria. Proposal of a new quantitative method for postural comfort evaluation. *International Journal of Industrial Ergonomics*, 48:25–35, 2015.

[4] M. W. Short and J. H. Cauraugh. Precision hypothesis and the end-state comfort effect. *Acta psychologica*, 100(3):243–252, 1999.

[5] S. A. Su and R. Furuta. A logical hand device in virtual environments. In *Proceedings of the ACM Conference on Virtual Reality Software and Technology (VRSTâĂŹ94)*, pages 33–42, 1994.

[6] P. Vink and S. Hallbeck. Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Applied ergonomics*, 43(2):271–276, 2012.

Figure 6: Correlation of Improved Metric in Test Data.

Figure 7: Correlation of Naive Metric Value in Test Data.

Figure 8: Correlation between Improved Metric Value and Total Time in Target Shooting
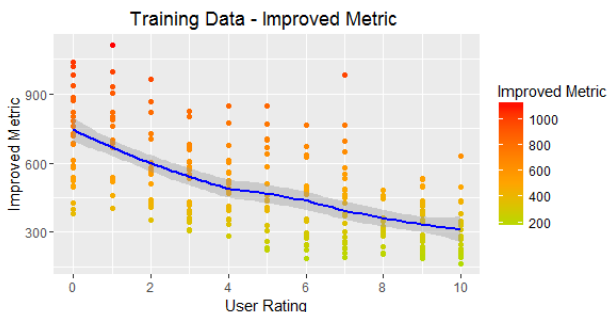

Figure 5: Correlation of Improved Metric Value in Training Data.
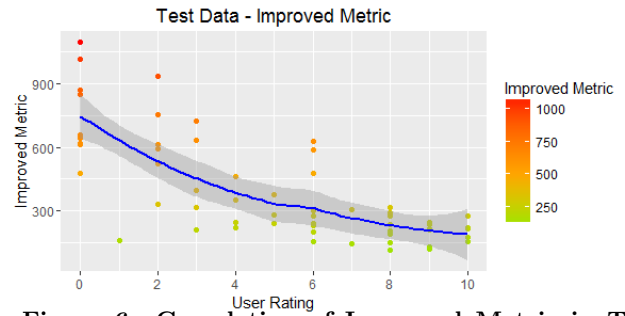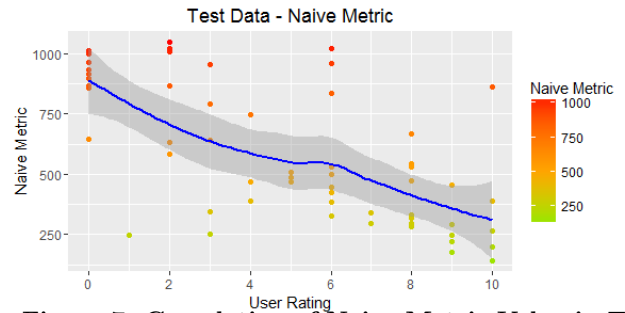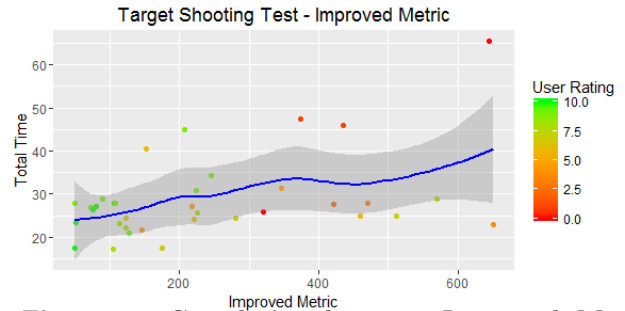The Line Shows the Smoothed Conditional Mean, Calculated by the `geom_smooth` Function in R.