A Basic Metric for Hand Comfort/Discomfort Evaluation

Exploring Short-Term Hand Posture Comfort and Discomfort

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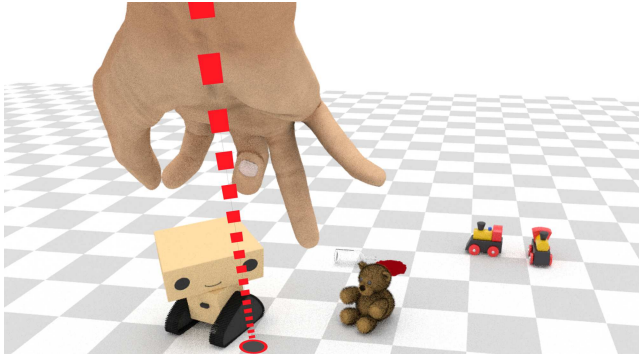Munich, Germany
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Figure 1: Controlling a Robot using Hand Postures

ABSTRACT

We propose an early, straightforward metric for quick short-term comfort and discomfort evaluation of non-resting hand postures. The metric is further improved using data from user studies. Comparing subjective user ratings with the metric indicates the metric to be a fitting model for perceived comfort and discomfort. Our results also indicate that there is an effect of hand comfort and discomfort on precision and performance in a 3D target pointing task.

Keywords

comfort/discomfort metric, hand posture

1. INTRODUCTION

Using a traditional desktop computer, users have access, through the keyboard, to a number of shortcuts and macros thanks to numerous keys, and through the mouse to a host of context menus that allow for easily launching various commands.

The nature of contexts such as virtual reality and human-robot interaction, however, does not allow for so many physical buttons or for accuracy when accessing context menus.

In such contexts speech and hand gestures are common interaction concepts. Nonetheless speech interaction is limited when it comes to spatial navigation, such as when commanding a robot to execute some household task (Figure 1). Pointing with hands is much more efficient in such situations and hand postures can be used to add additional expressiveness to pointing gestures. The main challenge for gestures and postures has been fighting physical forces that cause fatigue or discomfort. The latter limit user experience and precision [4]. Even though comfort and discomfort are often taken into consideration by designers, there are only a handful evaluation methods [3].

This work aims to support the creation and evaluation of a hand posture vocabulary for efficient pointing-based posture interaction. For that we propose an early hand posture comfort/discomfort metric that allows for quick and objective hand posture evaluation. We combined state of the art comfort/discomfort models with current hand anatomy and ergonomics knowledge to create models that can predict hand comfort and discomfort given a specific posture. Based on our model we created a naive metric, which 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 hand pointing task.

We first explain the theoretical basis of our comfort/discomfort model and then proceed to derive our naive metric. Following that, we explain the methodology used for optimizing and validating the metric as well as for showing the metric's influence on performance in a pointing task. Finally, the results will be analyzed and discussed, before our findings are evaluated and put in a greater context.

2. HAND POSTURE COMFORT/ DISCOMFORT METRIC

The structure of the metric proposed is based on current ergonomics models [6]. These models define comfort as a "pleasant state or relaxed feeling of a human being" mostly caused by subjective impressions and expectations. Discomfort is defined as "an unpleasant state of the human body" resulting from physical stress. Using this information combined with knowledge of hand anatomy, we broke down hand comfort and discomfort in a non-resting hand into the following four components: Deviation from Range of Rest Posture (RRP), Inter Finger Angles (IFA), Finger Hyperextension (HE) and Finger Abduction (FA). These components will be explained in the following sections.

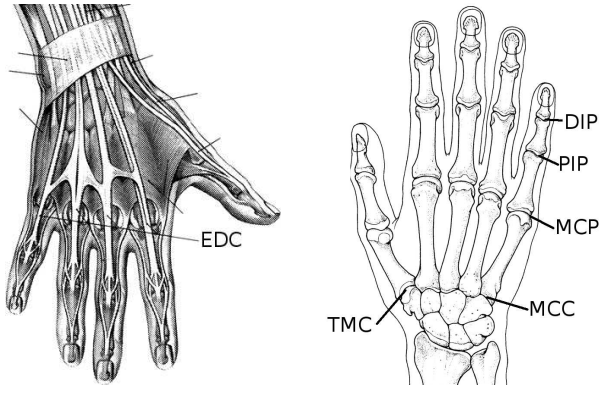For the computation of our metric we used a simplified 21

Figure 2: Hand Anatomy (taken from [2])

degree of freedom angle based hand model, similar to the model described by Su et al. [5], as it makes reading joint angles trivial. Furthermore, the 21 DOF angle based hand model was simply handled as a vector of 21 `float`s.

2.1 Deviation from Range of Rest Posture

Range of Rest Posture (RRP), as defined by Apostolico et al. [1], is a range of angles for an articular joint[1], where the joint "can be considered statistically in rest". The resulting relaxation of muscles and tendons creates maximum comfort in this particular joint. In our case, we considered the non-resting human hand to have a specific RRP for each finger joint, when the palm is facing downwards. Combining the RRPs of each finger joint for the entire hand results in a set of relaxed hand postures where comfort is maximized.

For articular joints perceived comfort decreases when deviating from the RRP and it minimizes at the bounds of the total 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 Motion Controller. The metric **RRP(x)** was simply computed by calculating the minimum euclidean distance of a hand denoted as a multi-dimensional vector "x" to the RRP set. For simplicity we assumed comfort to linearly decrease with distance to the RRP in our metric.

2.2 The Inter Finger Angles

The hand has a very compact and highly connected system of muscles and tendons that limits the individual movement of fingers (Figure 2). Aside from the thumb, fingers share *most* of their flexor and extendor muscles. Despite that minor individual flexion and extension (Figure 3) of 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*) the finger tendons are even interconnected on the back of the hand (Figure 2).

Based on this, we expect hand postures with high bending differences of adjacent fingers to cause stress of tendons and muscles, resulting in discomfort.

The **inter finger angle component IFA(x)** was computed by first adding up the flexion/extension angles of

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

MCP (*metacarpophalangeal*, PIP(*proximal interphalangeal*) and DIP (*distal interphalangeal*) joints (Figure 2) for each finger. We then added 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 its neighbors multiplied with an estimated weight coefficient. The importance of this differentiation can be seen when the fist is closed. Extending the ring finger from a closed fist is much harder than extending the index finger.

2.3 Finger Hyperextension

As stated by LaViola, **hyperextension** (Figure 3) "*puts more strain on the* [MCP] *joints and tendons than the hand is accustomed to*" and therefore causes discomfort [2]. Even though this might seem redundant to the deviation from RRP on first sight, hyperextension takes an increased toll 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 added up the flexion/extension angles of the fingers' MCPs 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.

Abduction was taken into consideration, analogue to the hyperextension, as full abduction creates substantially more discomfort than full adduction (Figure 3).

We computed the **abduction** component **FA(x)** by adding up the absolute abduction/adduction angle for the finger. This is possible as a fully adducted finger has an abduction angle of 0 in our model.

2.5 Naive Metric

After determining the single components, we designed our metric to be the added up component values ($RRP, IFA, ...$) multiplied with weighting coefficients ($c_{RRP(x)}, c_{IFA(x)}, ...$). These weighting coefficients were estimated for the **naive metric.**

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

We hypothesize that the resulting metric will correlate with user perception, having the value 0 as maximum for comfort and minimum for discomfort.

2.6 Improved Metric

Even though the naive metric contains the causes of comfort and discomfort, it still lacks deeper consideration for
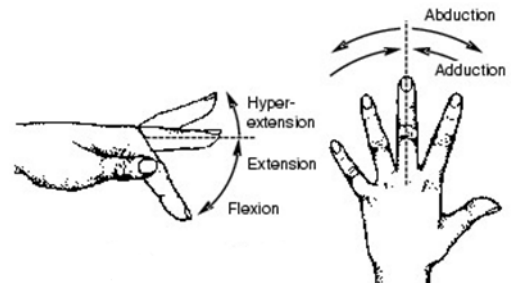

Figure 3: Hyperextension and Abduction (from [2])

the anatomical differences between the fingers. The concept of improvement extends the thought process already used for inter finger angles: instead of applying the metric to the whole hand, we consider the contributions from individual fingers and weight them with importance coefficients.

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

In our case we have five comfort values and a total of twelve 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. We used data obtained from user studies 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 first task (hand posture evaluation), the subject would be shown a randomly generated hand posture on screen. We used our naive metric to ensure a homogenous distribution of expected comfort and discomfort. The subject was asked to mimic the hand posture with his or her dominant hand and then rate the posture. As we did not expect the subjects to be familiar with current comfort and discomfort models, we asked them to rate hand postures on an intuitive scale ranging from 0 (very uncomfortable) to 10 (very comfortable). This was chosen over an ordinal Likert-like scale, because numerical values were needed for the metric's improvement and it's verification. The subject was told to rate the hand posture with 0 points if he or she was unable to reproduce it. Before beginning the hand posture evaluation, subjects were asked to form two hand postures so that they have a comfort/discomfort reference for the actual test. The first hand posture was a completely relaxed hand, the second hand posture was a randomly generated hand, that was challenging to mimic (such as the posture in figure 1).

In the second task (target shooting), the subjects were 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) with that specific posture. This specific task was chosen due to its similarity to real world tasks, where quick and precise spacial commands have to be issued. We tracked the subject's hand using an **ART Tracking Device**. The software showed subjects a minimalistic representation of their hand position and indicated the forward direction of their hand with a ray. Subjects were seated, with the elbow rested on a table. They 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 subject would not break the posture.

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 small and told the subjects to perform the test as quickly as possible.

We conducted a total of two user studies, a pilot study featuring the hand posture evaluation only and the main study, where both target shooting and hand posture evalu-
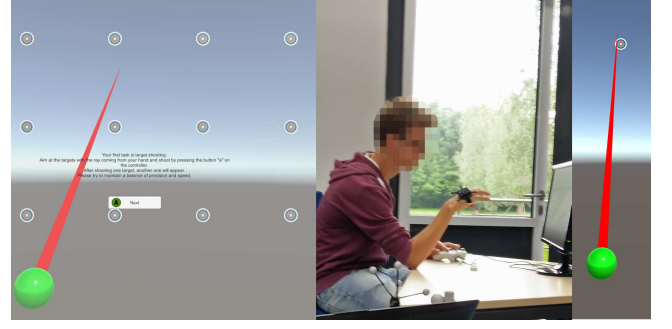

Figure 4: A Participant performing Target Shooting

Table 1: Weighting Coefficients of Improved Metric

	Thumb	Index	Middle	Ring	Pinky
RRP	0.631	-1.837	1.176	-3.021	1.288
IFA	-	0.547	0.216	1.670	-0.864
HE	-	-1.637	-2.685	10.401	-1.837
FA	-	-0.864	-3.857	0.0388	2.517

ation were tested. The studies were conducted with 12 and 15 participants respectively, whereof 2 and 5 were female. The participants' mean age was ??? and 21. Subjects were informed about the aim of the study as well as their specific objectives beforehand.

For improving the metric the main goal was to fit the calculated metric values to the user evaluations as closely as possible. For this, a least squares algorithm was used to find the optimal weighting coefficients based on the 250 data sets from the main study (training data). Afterwards, the metric was tested against the 60 data sets of the pilot study (test data).

4. RESULTS & DISCUSSION

For statistical analysis of the results, the Pearson correlation was used[2]. The results are displayed in Figure 5-8, with the single samples shown as dots and the line indicating the smoothed conditional mean, calculated by the `geom_smooth` function in R. Unsurprisingly, the calculated values for the improved metric strongly affect the users comfort ratings, that were used to generate this metric (Figure 5). However, differences in anatomy and mindset of the participants and the limitation of hand posture ratings to 11 discrete steps introduced some noise to the data.

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[2]The effect size is determined by the correlation coefficient. A correlation is significant if $p < 0.01$
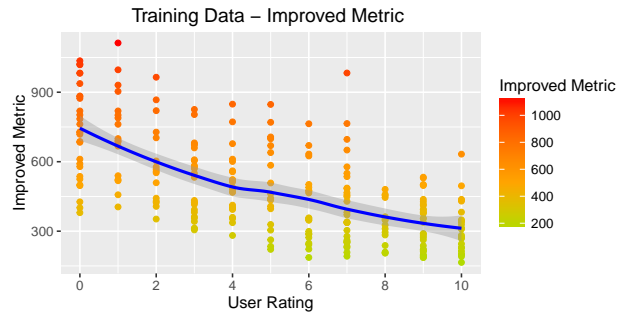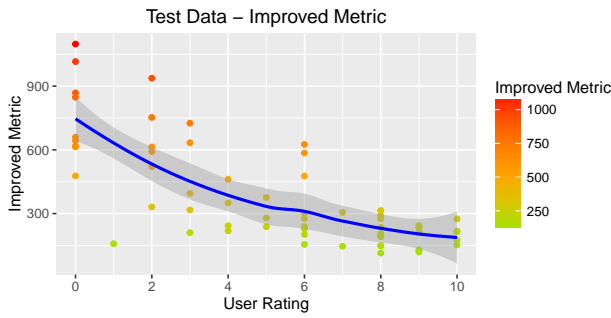

Figure 5: Improved Metric and User Rating in Training Data.
Correlation Coefficient: -0.645, p-value: $< 2.2e{-}16$

Figure 6: Improved Metric and User Rating in Test Data.
Correlation Coefficient: -0.748, p-value: 5.89e-12

The computed weighting coefficients for the improved metric can be taken from Table 1. Due to the small number of participants, the coefficients are very noisy and don't seem to make much sense. It can also be seen that the IFA coefficients are generally less noisy than those of HE or FA. This indicates, that the different components are perceived differently and that the metric has room for improvement.

Despite the noise, the created metric also holds its large effect on the user ratings even when applied to the test data (Figure 6). This shows, that the improved metric is a valid extrapolation of the training data and can be used to predict the perceived user comfort and discomfort of a certain hand posture.

When looking at the naive metric, it can be seen that it predicts the user ratings in a similar way (Figure 7). However the improved metric creates a better prediction, as it reduces the metric values standard error.

The results from the target shooting task (Figure 8) shows that participants with harder hand postures generally took longer to finish. The large effect size is also confirmed by the Pearson correlation. This indicates that comfort and discomfort, as measured by our metric, significantly 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 number of participants. Further work is required before strong conclusions can be made.

5. CONCLUSION & FUTURE WORK

The main goal of this paper was to create a basic metric for quick and objective evaluation of hand posture comfort and
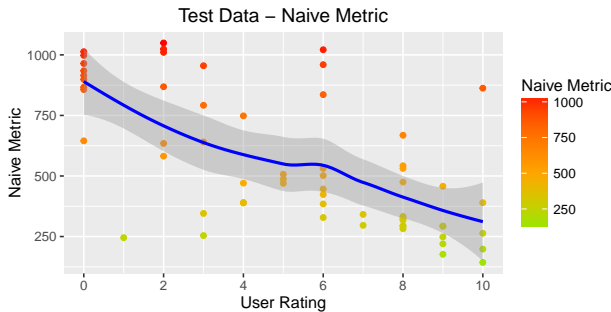
Figure 7: Naive Metric and User Rating in Test Data.
Correlation Coefficient: -0.665, p-value: 6.73e-9

Figure 8: Improved Metric Value and Total Task Time in Target Shooting.
Correlation Coefficient: -0.665, p-value: 6.73e-9

discomfort. Furthermore we demonstrated the metric's 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 hand anatomy and state of the art comfort and discomfort models and used data from a user study to improve it. Results from the testing user study suggest the improved metric to be a valid extrapolation 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 different contexts in other papers.

This work was only a first step for exploring hand posture comfort and discomfort. The metric created is still primitive and has some room for improvement. Furthermore only the short-term effects of comfort and discomfort combined were studied. An important next step would be to investigate the long- and short-term effects of comfort and discomfort separately in order to create more sophisticated models and metrics.

6. REFERENCES

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