An interactive assessment of robustness and comfort in human grasps

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Abstract

This paper presents a system that interactively assesses the quality of grasping of an object while someone grasps the object in his/her bare hand. Many previous studies presented various methods for assessing grasps, but most are used for simulation and post-assessment. These methods are unsuitable for interactively assessing the usability of products. This report shows an interactive system that measures and assesses human grasps by a band sensor with distance sensors aligned in line. The proposed system assesses robustness and comfort of measured human grasps online. The effectiveness of the proposed system was verified in a simulation and a physical experiment.

Keywords: digital hand, grasp quality assessment

1 Introduction

To quantitatively assess usability of a handheld product, it is useful to measure the actual behavior of humans using the product and analyze reconstructed measured grasps with a digital hand model on a computer. By using commercially available systems, these processes (measurement, reconstruction, and analysis) can be executed one by one, which means it takes a while to reflect some findings from the measurement to change design. For example, an optical motion capture (MoCap) system is often used for measurement. The MoCap system is superior in terms of accurate measurement but requires many markers to be attached on the hand, which encumbers natural behavior. In addition, it requires time-consuming manual marker labeling, which is necessary to convert its position data into posture data to be assessed. However, if on-site natural behavior can be measured and grasp quality metrics can be used interactively then and there, the product design cycle is expected to be changed and accelerated: users of the product can freely try various way of grasping, and designers can test their ideas by observing actual users' reactions with quantitative assessment data.

This study, therefore, aims at developing an interactive assessment system for bare-hand grasping. To measure a grasp of an object by a bare hand, a “Wrap & Sense” system (MIYATA et al., 2016) is extended so that sensor density increases. To assess product usability, we focus on robustness and comfort of the grasp and implement indices that suit interactive calculation. The proposed system is validated through physical experiments.

2 Methods

2.1 Grasp measurement system: Wrap & Sense

For bare-hand grasp observation, several systems have been developed that use RGB-D camera(s) or color video images (e.g. WANG et al. 2013). As cameras are assumed to be fixed in the environment, such systems are not robust to environmental changes including changes in location of the user's body and the target object. Wrap & Sense can avoid this occlusion problem by attaching band-style sensor equipment on the object so that it detects the side edge of the hand.

A profile of the Wrap & Sense system used in this study is shown in Fig. 2.1. The band-style sensor equipment was comprised of 16 infrared distance sensors. All the distance sensors were directed in parallel along the object surface, and each measured the distance between itself and a point on the side edge of the hand from the thumb tip to the index finger. By using a 3D model of the target object with the location and direction definition of each sensor, each distance was converted into a position of the detected point. The detected points were used to estimate the plausible location of each feature point defined on the hand model. The subject's hand model was generated by deforming a generic model through an optimization to satisfy 40 hand dimensions estimated from four directly measured dimensions: hand length, hand width, and breadth and a depth of the middle finger's proximal interphalangeal joints (NOHARA et al., 2016). The whole hand posture was reconstructed by minimizing distances between corresponding points, resulting in the aligned hand model.

Compared with the original Wrap & Sense system, a smaller distance sensing module (Sharp Corporation, GP2Y0E02A) was used, and the number of sensors was increased for higher sensor density.

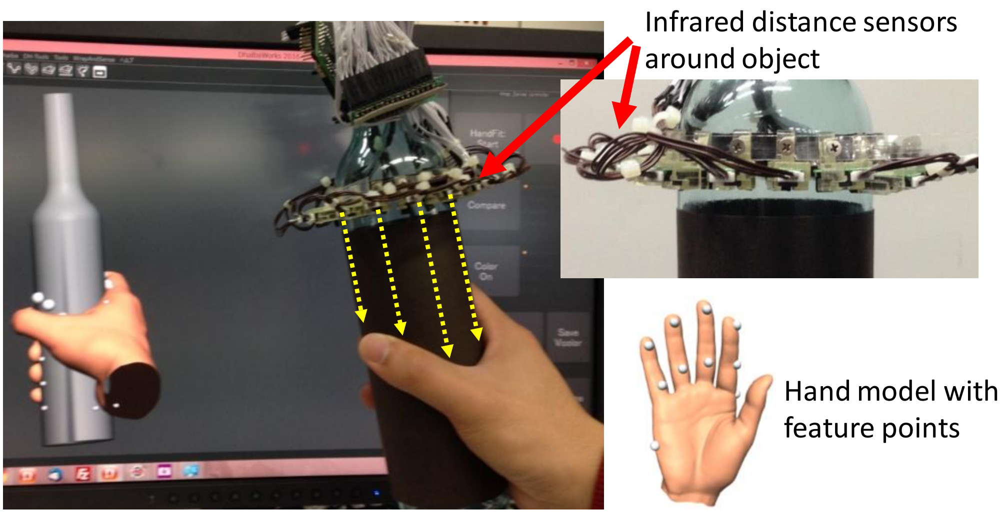


Fig. 2.1 Profile of Wrap & Sense system used in this study

2.2 Assessment indices for grasp: robustness and comfort

Grasp quality indices were originally developed in robotics (SHIMOGA, 1996) but have been gradually extended to human grasps (LEON et al., 2012; KANAI et al., 2014). As these metrics were for offline assessment and were not necessarily suitable for interactive assessment, two indices were developed and implemented here to assess robustness and comfort in human grasps. On implementation, contact between the hand and an object was modeled as a set of point-contacts with friction. The contact region was derived using surface vertices of a hand model and point clouds generated on an object model.

The robustness of the grasp was defined as the resistant capability of contact forces and known external forces (e.g. gravity) against unknown disturbing force and torque (MAEDA, et al., 1996). As shown in Fig. 2.2, this corresponded to a derived radius of a six-dimensional inscribed hypersphere in the wrench space with its center located at the known external force and torque. At each contact point, the generable resistant force can be expressed as a friction cone assuming Coulomb friction. To reduce computational cost, each friction cone was approximated as a regular pyramid when considering wrench space, and the six-dimensional inscribed hypersphere was approximated as a hyperpolyhedron with a finite number of vertices. Then the robustness index (approximated radius of the inscribed hypersphere) was calculated by solving linear programming problems.

As for the grasp comfort index, we consider “maximum pain” by using the maximum contact pressure and “muscle load” by using the ratio of the generated force by each link to its maximum generable force. The comfort index was calculated by solving a linear programming problem that minimized the weighted summation of the maximum ache and muscle load terms.

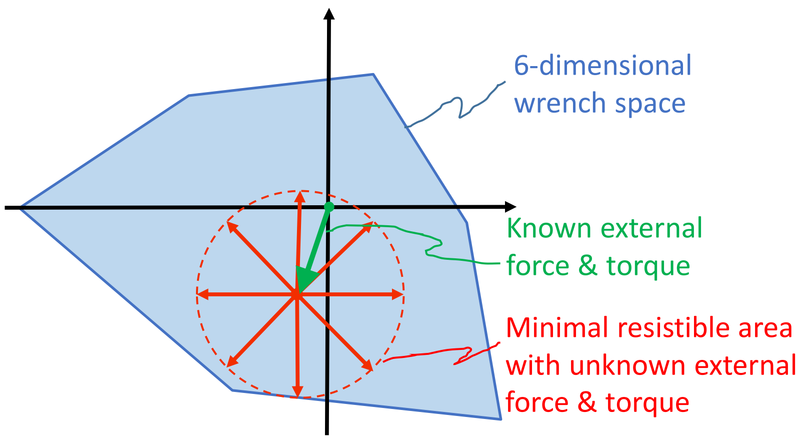


Fig. 2.2 Two-dimensional schematic view of proposed grasp robustness index

3 Experimental Results

The validity of the proposed system was tested through two experiments. The friction coefficient in both experiments was set to 0.3.

3.1 Assessment indices validation

First, a simulation experiment was conducted to test the validity of the implemented quality indices by showing the difference in accordance with the object shape. Seven different prisms shown along the top of Fig. 3.1 were tested that had a cross-sectional shape (hexagram) with the same circumradius (30 mm) but different vertex angles from 0 deg (acutest hexagram) to 120 deg (hexagon). The same hand posture that was captured by the MoCap system was used for the grasp of all the objects. In the right side of Fig. 3.1, the grasp of the prism with vertex angle at 100 deg is shown. A 5 N gravitational force along a longitudinal axis (downward to the wrist adduction direction) was given as a known external force.

Fig. 3.1 shows the calculated indices' values. The robustness index is better when larger, and the comfort index is better when smaller. For the comfort index, better scores at obtuse vertex angles than at acute ones were considered to be natural in terms of the human preference to avoid aches. For the robustness, better scores at obtuse vertex angles were considered to be natural because they offer a larger contact area. These intuitively-natural tendency indicated the validity of the proposed indices for grasp assessment.

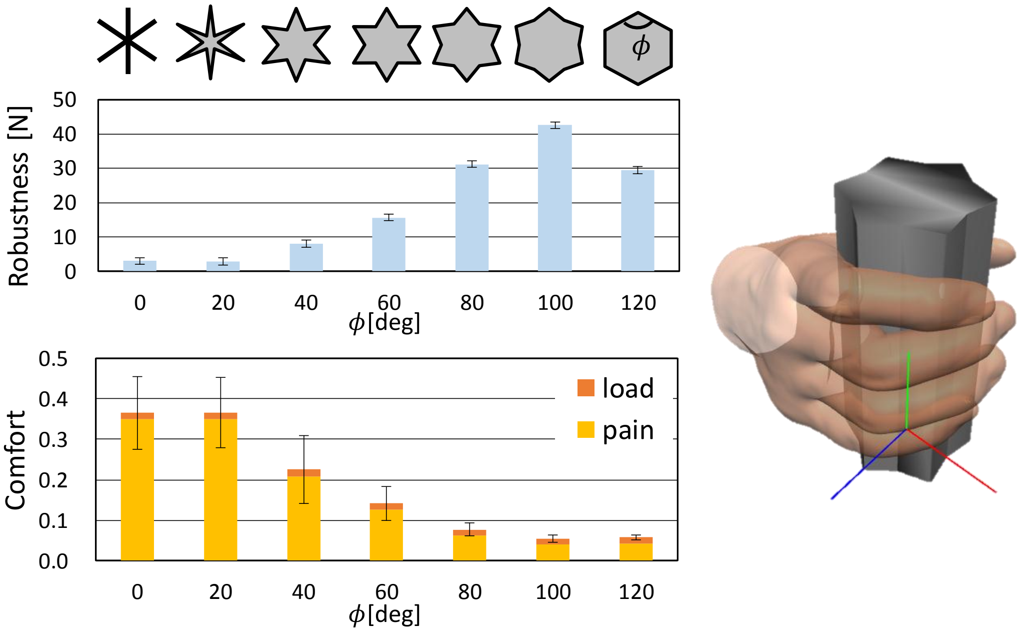


Fig. 3.1 Robustness and comfort indices according to object shape

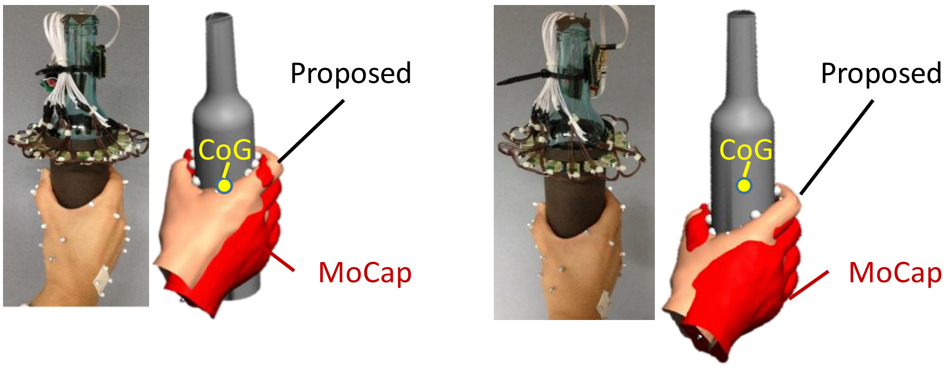
3.2 Feasibility validation of interactive grasp assessment system

Feasibility of the proposed system in terms of interactivity was tested through a physical experiment to assess grasps of a bottle equipped with the Wrap & Sense sensor system. Two grasping locations (postures 1 and 2) in Fig. 3.2 were captured and compared. In the indices calculation, 10 N force along a longitudinal axis of the object (downward to the wrist adduction direction) was given at the center of gravity of the object as a known external force (gravity).

In Fig. 3.2 (a) and (b), reconstructed postures are shown in the right side, respectively. In each figure, a hand model in flesh color means a captured result by the proposed system and that in red means a result by a MoCap system. The proposed system reconstructed the actual system well.

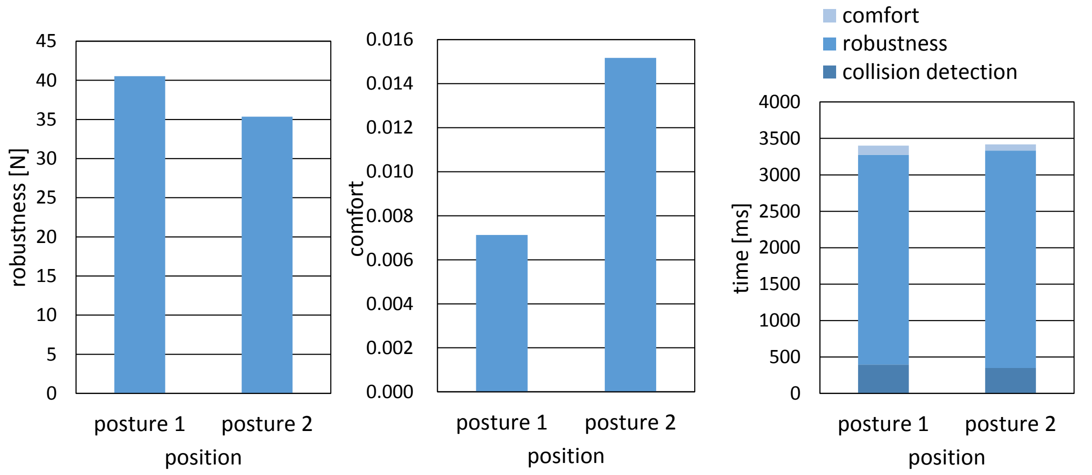
According to the calculated indices shown in Fig. 3.3 (a) and (b), posture 1 scored better in both indices. This was natural considering the relative configuration of the hand with the center of gravity of the object because posture 1 was closer to the center of gravity of the object than posture 2.

Fig. 3.3 (c) shows the computation time consumed for each index. The proposed system was executed on a 64-bit personal computer (Intel® Core™ i7-3920XM 2.90GHz). The robustness index calculation sometimes took a rather long time, such as 3000 ms. This calculation time could be reduced by thinning the density of points generated on the object model for contact region derivation or decreasing the robustness estimation accuracy. The system could then be considered to be interactive.



(a) Posture 1 (b) Posture 2

Fig. 3.2 Compared postures in system feasibility validation experiment



(a) Robustness (b) Comfort (c) Computation time

Fig. 3.3 Proposed assessment indices and computation time

4 Conclusion

This paper presented an interactive grasp assessment system. In addition to extending the previously developed Wrap & Sense measurement system by increasing the sensor disposition density, grasp robustness and comfort indices were developed and implemented with the system and validated through a simulation and a physical experiment.

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