摘 要

手势作为一种自然直观的交互方式，在人机交互的诸多场景中展现了巨大的应用前景。但准确、实时地跟踪全手行为并进行自然的手势交互，目前仍存在许多难点。因此，本文面向手部跟踪和手势交互领域，研究全手行为追踪技术，探究空中手势交互方法。

本文主要工作如下：

1）研究了一种全手行为跟踪优化方法。首先，本文依据传感器姿态估计方法，构建全手行为跟踪算法。其次开发手部约束特性，将手部约束作为先验知识融合进全手行为跟踪算法中，作为全手行为跟踪优化算法。最后通过实验验证本文提出的优化算法针对 PIP 误差显著降低，融合约束的优化方法($M = 0.2321, SD = 0.1442$)相较于未优化方法($M = 0.2685, SD = 0.1323$)误差降低了 13%，表明姿态优化方法更加贴近真实手部姿态。

2）设计了一套以用户为中心的手势集，并提出了空中手势交互中的坐标映射方法与手势实现方法，最后通过提取震颤信息识别用户交互意图，为空中手势交互中的 MidasTouch 问题提出一种解决方法。实验结果表明，通过提取的震颤特征在区分用户有无交互意图行为的准确率达到了 97%，通过震颤特征区分用户交互意图强弱的准确率达到了 76.8%。

3）设计并实现了基于姿态的空中手势交互系统 iInteractiveGloves。在该交互系统中，实现了空中手势交互的五类基本功能，并且针对该空中手势交互系统设计了一种无线传输数据手套，为基于姿态的空中单手手势交互提供支持。

本研究面向基于姿态的全手行为跟踪与手势交互技术，通过开发手部约束特性，提出一种全手行为跟踪优化算法，通过实验验证了优化方法的有效性；其次通过用户实验设计以用户为中心基于姿态的手势集合；最后利用震颤特征识别用户行为中的交互意图，通过实验表明这种方法具有可行性。本研究对于全手行为跟踪技术以及空中手势交互技术具有参考意义。

关键词： 人机交互；手势交互；手部姿态；行为跟踪；交互意图

Abstract

Human gesture, as an intuitive interaction mode, has shown great application potential in human-computer interaction across various scenarios. However, accurate and real-time tracking of full hand articulation and achieving natural gesture interactivity still face many challenges at present. Therefore, this paper focuses on the domains of hand tracking and gesture interaction by studying full hand motion tracking techniques and exploring mid-air gesture interaction methods.

The main works are as follows:

1）An optimization approach for full hand tracking is studied. First, a tracking algorithm is built relying on sensor pose estimation methods. Then, hand constraints are modeled and integrated as prior knowledge to refine the tracking, forming an optimized tracker. Experiments show the optimization ($M = 0.2321, SD = 0.1442$) significantly reduces PIP joint errors by 13% compared to the unoptimized version ($M = 0.2685, SD = 0.1323$), better approximating real hand poses.

2）A user-centric mid-air gesture set is designed and techniques for spatial mapping and gesture implementation are proposed for mid-air interactions. Furthermore, by extracting tremor information, user interaction intents are recognized, offering a potential solution to “Midas Touch” issues in gesture spaces. Results demonstrate 97% accuracy in distinguishing intentional and non-intentional interactions and 76.8% accuracy in grading interaction intensity levels.

3）An mid-air gesture interaction system called iInteractiveGloves is implemented based on hand posture tracking. Five basic function classes are supported for the mid-air gesture interface. Moreover, a wireless sensory glove is designed to acquire and transfer the hand movement data.

Through modeling hand constraints and proposing a tracker optimization approach, this research explores robust full hand motion tracking and understanding. The proposed user-centric gesture design and interaction intent recognition via tremor sensing also showcase promising directions toward more natural and fluid mid-air gestural interactions between human and machines.

Key words: Human-Computer interaction;Gesture recognition; Hand attitude; Motion tracking; Interaction intention