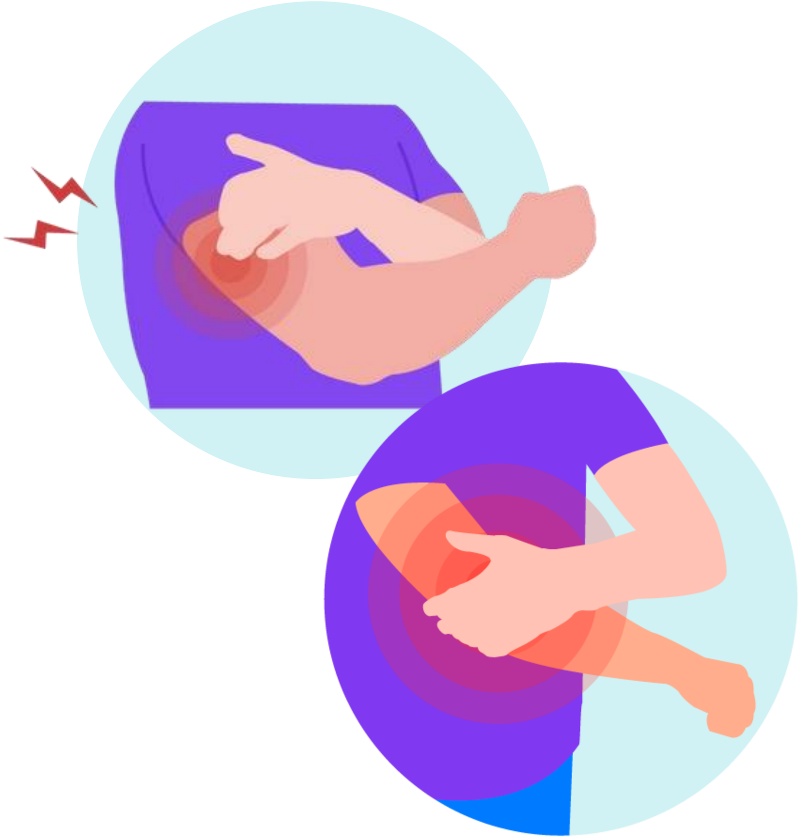
人因工程课程实验系列——

消耗耐力测定实验

- 东南大学 周小舟

背景

低成本手势追踪系统的大量出现使得空中手势交互成为一种新型自然用户界面(NUI)，被广泛应用于虚拟现实或增强现实的场景中。然而，用户在进行空中手势输入时经常报告疲劳和手臂的沉重感，这种情况被称为大猩猩手臂效应。手臂疲劳问题的存在严重影响了手势交互中的用户体验。目前，测量手臂疲劳的方法主要有生理指标法(心电、肌电)和主观问卷法(NASA-TLX、Borg量表)，这些方法并不适合空中手势疲劳的评估。因此，有研究者引入消耗耐力CE的概念，并提出了一种基于Kinect的手臂消耗耐力测量方法，这种方法有效地量化了手臂疲劳，为手势设计提供参考。



消耗耐力(Consumed Endurance, CE)

消耗耐力

消耗耐力是由加拿大University of Manitoba课题组提出的一种量化空中手势交互过程中手臂疲劳的指标，并经过实证检验证明消耗耐力CE测试结果和Borg量表自测结果密切相关。

其计算公式如下：

$$\text{Consumed Endurance(CE)} = \frac{\text{Interaction Time}}{\frac{1236.5}{\left(\frac{F}{F_{max}} * 100 - 15\right)^{0.618}} - 72.5}$$

其中：

Interaction Time为空中手势交互时间；

F为给定时间作用于肩部的力；

F_{max}为肩部最大的作用力，这依赖其他研究者测量所得的最大力，一般成年女性为87.2N，成年男性为101.6N。

Consumed Endurance: A Metric to Quantify Arm Fatigue of Mid-Air Interactions

Juan David Hincapié-Ramos, Xiang Guo, Paymahn Moghadasian, Pourang Irani
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Winnipeg, MB, Canada
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ABSTRACT
Mid-air interactions are prone to fatigue and lead to a feeling of heaviness in the upper limbs, a condition casually termed as the gorilla-arm effect. Designers have often associated limitations of their mid-air interactions with arm fatigue, but do not possess a quantitative method to assess and therefore mitigate it. In this paper we propose a novel metric, *Consumed Endurance* (CE), derived from the biomechanical structure of the upper arm and aimed at characterizing the gorilla-arm effect. We present a method to capture CE in a non-intrusive manner using an off-the-shelf camera-based skeleton tracking system, and demonstrate that CE correlates strongly with the Borg CR10 scale of perceived exertion. We show how designers can use CE as a complementary metric for evaluating existing and designing novel mid-air interactions, including tasks with repetitive input such as mid-air text-entry. Finally, we propose a series of guidelines for the design of fatigue-efficient mid-air interfaces.

Author Keywords
Gorilla-arm, mid-air interactions, mid-air text-entry, endurance, consumed endurance, SEATO mid-air keyboard.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): Evaluation/Methodology.

INTRODUCTION
The proliferation of low-cost gestural tracking systems has warranted the investigation of mid-air interaction as a new class of natural user interface (NUI) [20, 19]. This style of interaction has shown particular value in sterile medical rooms [7, 25], in educational settings [12], and in gaming environments [22]. Nonetheless, users engaged with mid-air input often report fatigue and a feeling of heaviness in the arm [9, 20], a condition coined as the gorilla-arm effect [9]. Gorilla-arm was first reported with the introduction of touch-screens, and was one reason for the early dismissal of such systems [1, 2]. Ignoring this factor in the design of mid-air interactions can also lead to the demise of this form of NUI.

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http://dx.doi.org/10.1145/2556288.2557130

Current approaches to assess arm fatigue include obtrusive measurements of bodily variables (heart-rate [30], oxygen level [16] or EMG [28, 32]) or the collection of subjective assessments (Borg [8], NASA-TLX [21] or Likert ratings). However, these methods have limited practical value for evaluating mid-air interactions as they require specialized equipment or have high variance. We propose a method for quantitatively characterizing the gorilla-arm effect based on the concept of endurance (Figure 1 and equation 1) [29, 17]. Endurance is the amount of time a muscle can maintain a given contraction level before needing rest. Using a skeleton-tracking system we capture users' arm motions and compute endurance for the shoulder muscles. *Consumed Endurance* (CE), our novel metric, is the ratio of the interaction time and the computed endurance time.

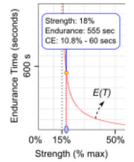


Figure 1. Endurance metrics for the mid-air interactions include Arm Strength, Endurance and Consumed Endurance (CE).

We validate CE against fatigue ratings as obtained using the Borg CR10 scale of perceived exertion. Further, we demonstrate CE's value as a complementary metric for evaluating mid-air interactions. For mid-air pointing and selection on a 2D plane, we used CE to identify the most suitable interaction parameters, such as arm extension, plane location and plane size. For example, users consumed the least amount of endurance when the arm was bent and operating on the interaction plane located midway between the shoulder and the waist. *Dwell* selections have the lowest CE for single hand interactions. We also demonstrate the value of using CE to inform the design of an endurance-efficient text-entry layout, SEATO (Figure 7-left). Users entering text with SEATO had lower CE than with QWERTY without compromising text-entry speed. Finally, we describe how our results inform the design of mid-air menus and other interactive systems. CE and other fatigue-related metrics are publicly available in a software toolkit (http://hci.cs.umanitoba.ca/projects-and-research/details/ce).

Our contributions include: 1) CE, a metric for characterizing shoulder fatigue or gorilla-arm effects resulting from mid-air interactions; 2) the use of CE to inform the choice of various mid-air interaction parameters; 3) an endurance-efficient mid-air text-entry layout, SEATO; and 4) guidelines for designing endurance-efficient mid-air interactions.

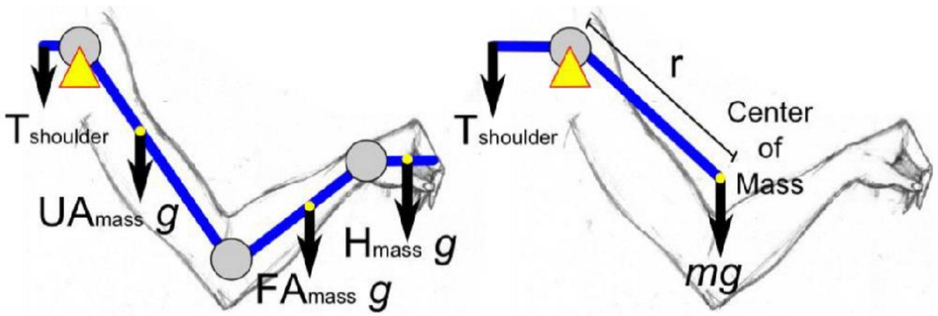
论文链接：Hincapié-Ramos J D, Guo X, Moghadasian P, et al. Consumed endurance: a metric to quantify arm fatigue of mid-air interactions[C]//Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2014: 1063-1072.

消耗耐力(Consumed Endurance, CE)

消耗耐力

其具体原理基于手臂的生物力学模型，如下图所示：

- 人的手臂可表示为包含上臂、前臂和手的复合旋转系统。所有力都施加在手臂的重心。
- 通过骨骼跟踪系统，我们可以提取各关节位置，根据关节位置计算t时刻的手臂重心位置，进而确定手臂重心速度和加速度。
- 在已知手臂力量的情况下，可以求解作用于手臂上的力矩，即F。
- 通过查表求解F_{max}，即可进一步求解出CE。



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基于Kinect的CE测量软件

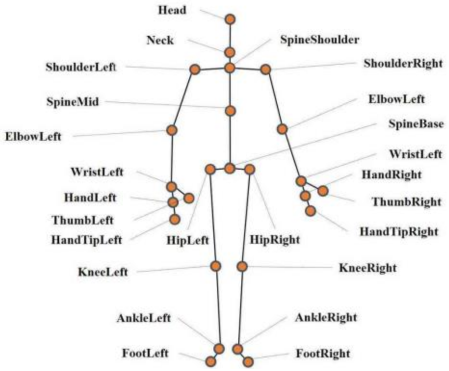
Kinect

Kinect是微软在2009年6月2日的E3大展上，正式公布的XBOX360体感周边外设，也是科研工作者研究体感交互的好工具。其采用计算机视觉技术来提取用户的骨骼节点，从而识别用户姿势。Kinect发展到现在，已经陆续推出Kinect v1、Kinect v2、Azure Kinect DK等版本，技术力也在一代代增强。

■ Kinect v1——Xbox360时期

■ Kinect v2——Xbox Ones时期

■ Azure Kinect DK



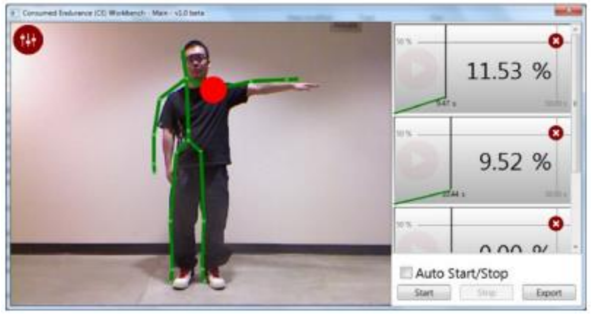
■ Kinect v1骨骼节点

基于Kinect的CE测量软件

Kinect测量软件

加拿大University of Manitoba课题组给出了消耗耐力的测试软件，该测试软件仅能接通Kinect v1来测量消耗耐力。

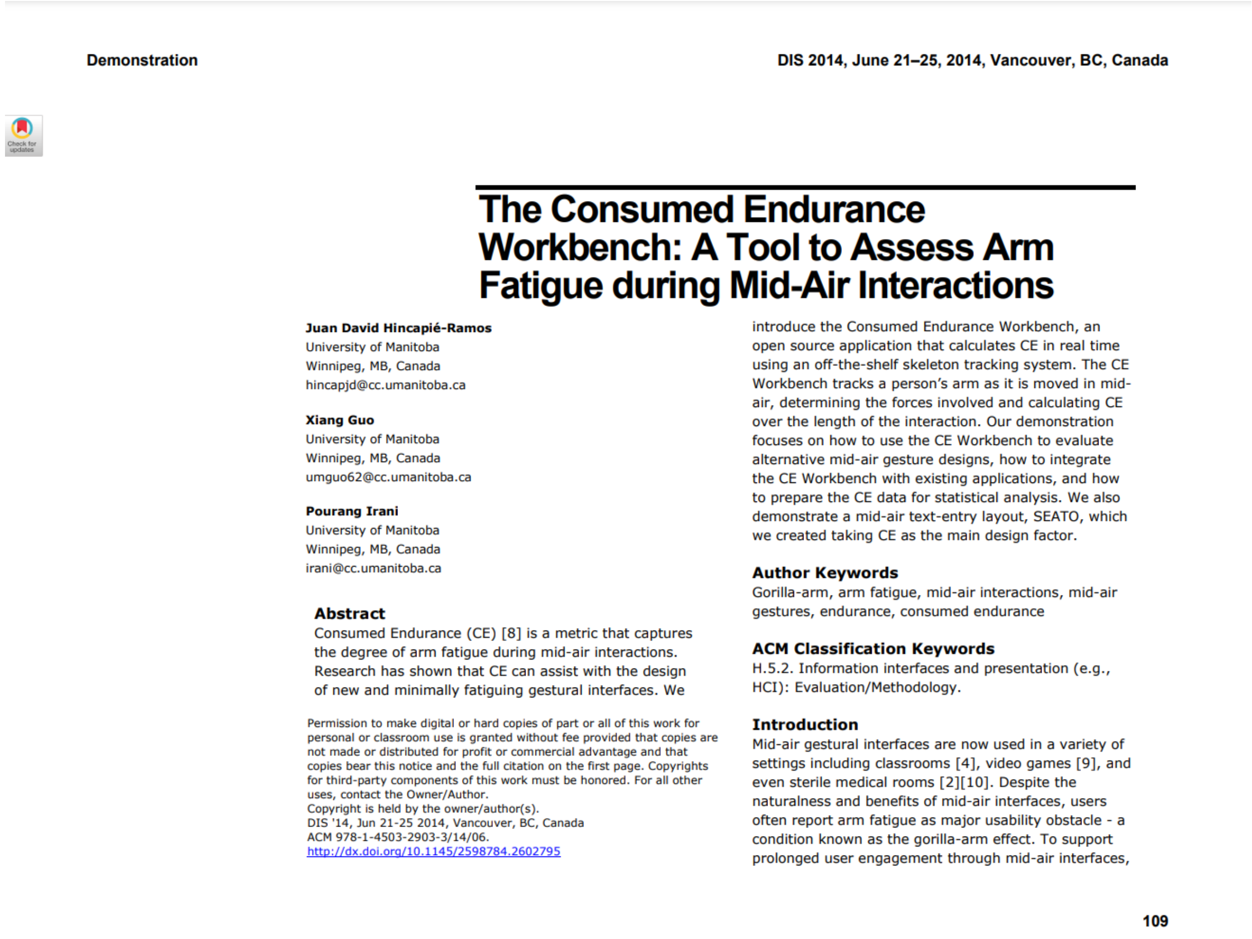
GitHub链接：https://github.com/hcilab-um/ArmFatigueCE



我们课题组的李荷露学姐对该程序做了些更改，实现每10s记录一次消耗耐力，程序百度网盘链接如下：

链接：https://pan.baidu.com/s/12LMD9DUxpkhcp0uUI8TD6Q

提取码：nms2



Demonstration

DIS 2014, June 21–25, 2014, Vancouver, BC, Canada

The Consumed Endurance Workbench: A Tool to Assess Arm Fatigue during Mid-Air Interactions

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Abstract
Consumed Endurance (CE) [8] is a metric that captures the degree of arm fatigue during mid-air interactions. Research has shown that CE can assist with the design of new and minimally fatiguing gestural interfaces. We introduce the Consumed Endurance Workbench, an open source application that calculates CE in real time using an off-the-shelf skeleton tracking system. The CE Workbench tracks a person's arm as it is moved in mid-air, determining the forces involved and calculating CE over the length of the interaction. Our demonstration focuses on how to use the CE Workbench to evaluate alternative mid-air gesture designs, how to integrate the CE Workbench with existing applications, and how to prepare the CE data for statistical analysis. We also demonstrate a mid-air text-entry layout, SEATO, which we created taking CE as the main design factor.

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http://dx.doi.org/10.1145/2598784.2602795

Author Keywords
Gorilla-arm, arm fatigue, mid-air interactions, mid-air gestures, endurance, consumed endurance

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): Evaluation/Methodology.

Introduction
Mid-air gestural interfaces are now used in a variety of settings including classrooms [4], video games [9], and even sterile medical rooms [2][10]. Despite the naturalness and benefits of mid-air interfaces, users often report arm fatigue as major usability obstacle - a condition known as the gorilla-arm effect. To support prolonged user engagement through mid-air interfaces,

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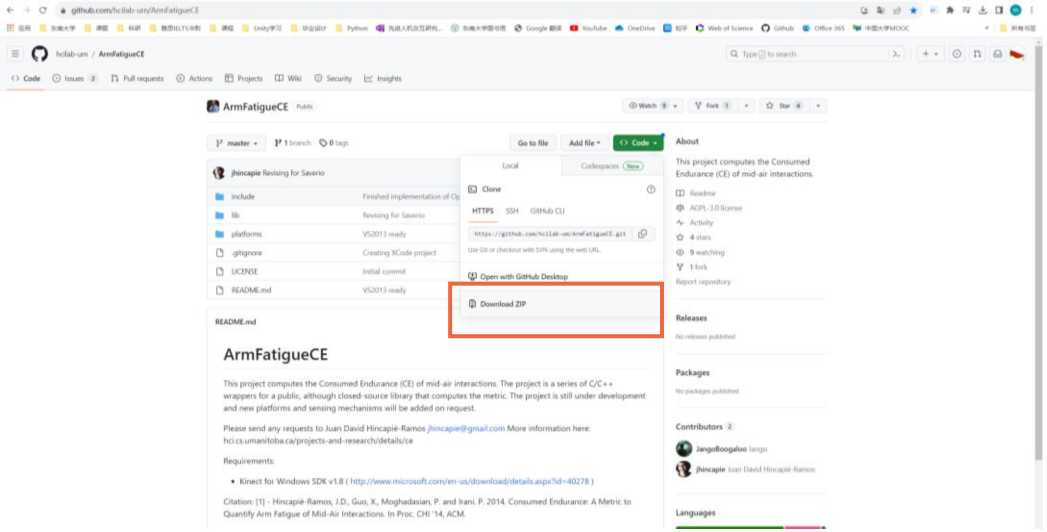
论文链接：Hincapié-Ramos, J. D., Guo, X., & Irani, P. (2014). The consumed endurance workbench: a tool to assess arm fatigue during mid-air interactions. In Proceedings of the 2014 companion publication on Designing interactive systems (pp. 109-112).

消耗耐力测试实验

步骤一：下载实验程序



README.md

ArmFatigueCE

This project computes the Consumed Endurance (CE) of mid-air interactions. The project is a series of C/C++ wrappers for a public, although closed-source library that computes the metric. The project is still under development and new platforms and sensing mechanisms will be added on request.

Please send any requests to Juan David Hincapié-Ramos jhincapie@gmail.com More information here: hci.cs.umanitoba.ca/projects-and-research/details/ce

Requirements:

- Kinect for Windows SDK v1.8 (http://www.microsoft.com/en-us/download/details.aspx?id=40278)

Citation: [1] - Hincapié-Ramos, J.D., Guo, X., Moghadasian, P. and Irani. P. 2014. Consumed Endurance: A Metric to Quantify Arm Fatigue of Mid-Air Interactions. In Proc. CHI '14, ACM.

步骤一

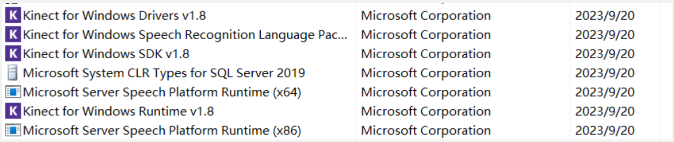
在GitHub链接或百度网盘下载消耗耐力文件夹，解压至电脑中。

注意：电脑需提前安装好Visual Studio 2019及之前版本，之后版本将不再支持.Net4.0框架，导致程序无法运行。

步骤二

安装Kinect的SDK

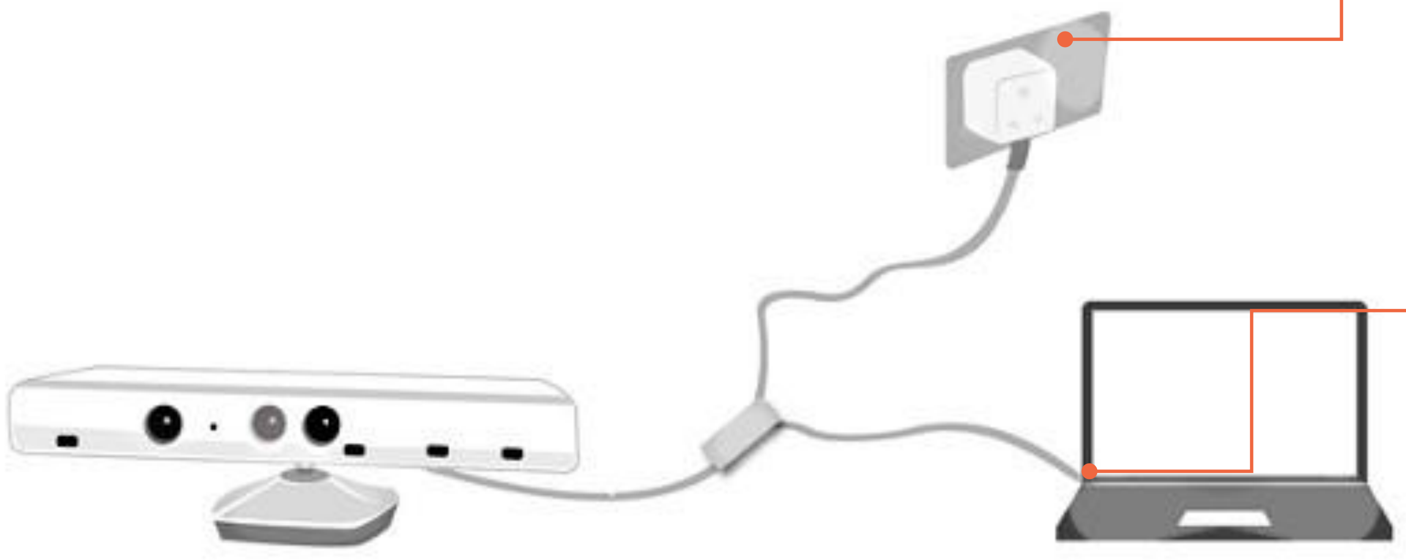
否则Kinect无法识别



Kinect for Windows Drivers v1.8	Microsoft Corporation	2023/9/20
Kinect for Windows Speech Recognition Language Pac...	Microsoft Corporation	2023/9/20
Kinect for Windows SDK v1.8	Microsoft Corporation	2023/9/20
Microsoft System CLR Types for SQL Server 2019	Microsoft Corporation	2023/9/20
Microsoft Server Speech Platform Runtime (x64)	Microsoft Corporation	2023/9/20
Kinect for Windows Runtime v1.8	Microsoft Corporation	2023/9/20
Microsoft Server Speech Platform Runtime (x86)	Microsoft Corporation	2023/9/20

消耗耐力测试实验

步骤二：将Kinect v1连接至电脑



步骤一

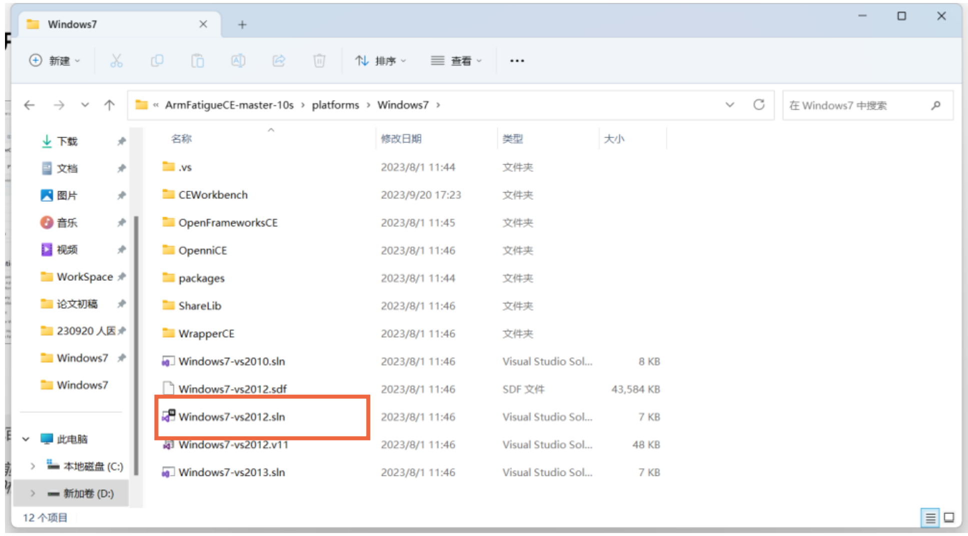
电源线连接至电源

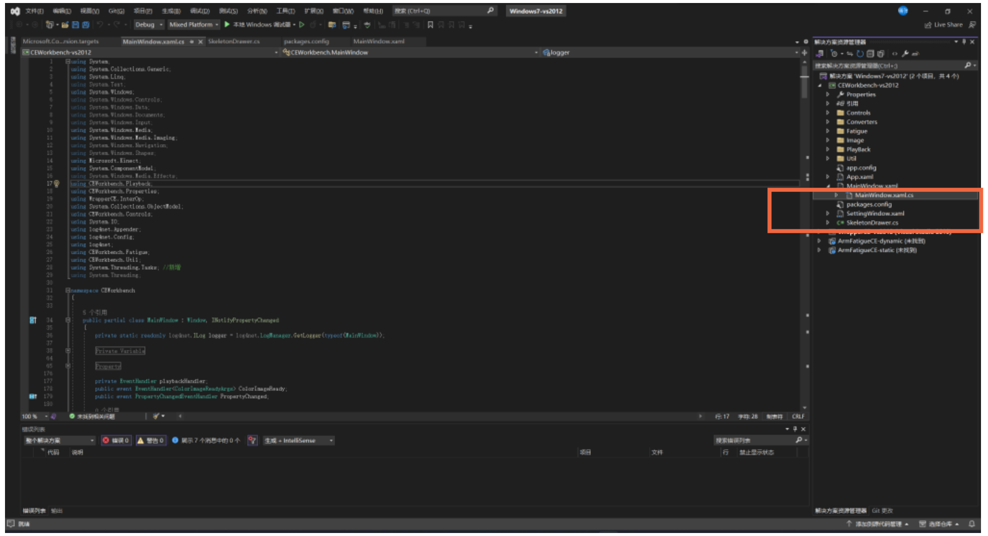
步骤二

USB线连接至电脑

消耗耐力测试实验

步骤三：打开消耗耐力测试程序





步骤一

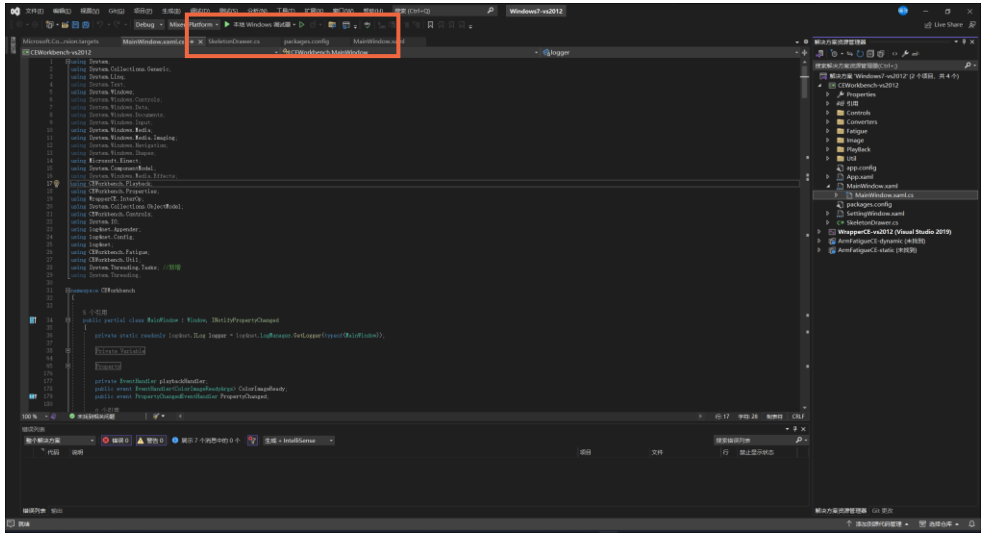
以本课题组李荷露学姐程序为例：
打开路径：ArmFatigueCE-master-10s\platforms\Windows7
选择Windows7-vs2012.sln，使用Visual Studio打开

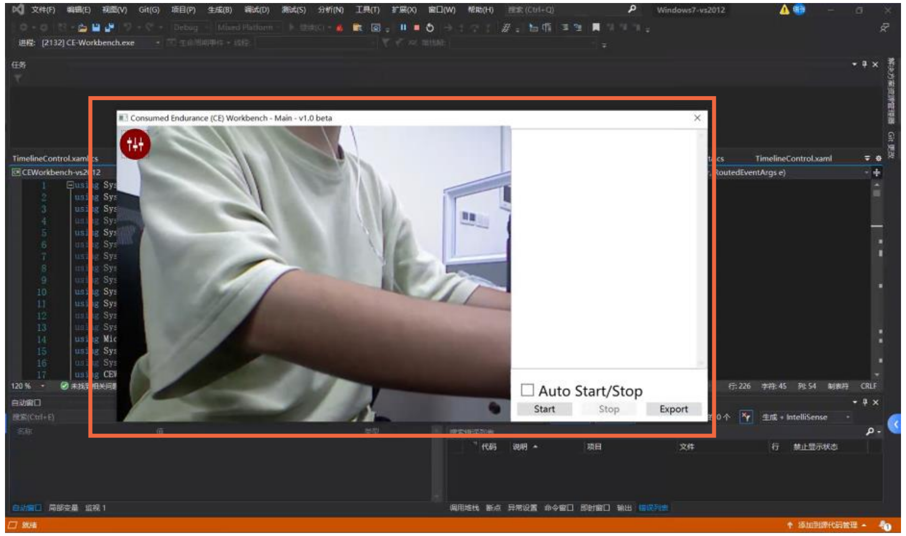
步骤二

在Visual Studio右侧解决方案管理器中，打开主程序：
CEWorkbench-vs2012→MainWindow.xaml→MainWindow.xaml.cs

消耗耐力测试实验

步骤三：打开消耗耐力测试程序





步骤三

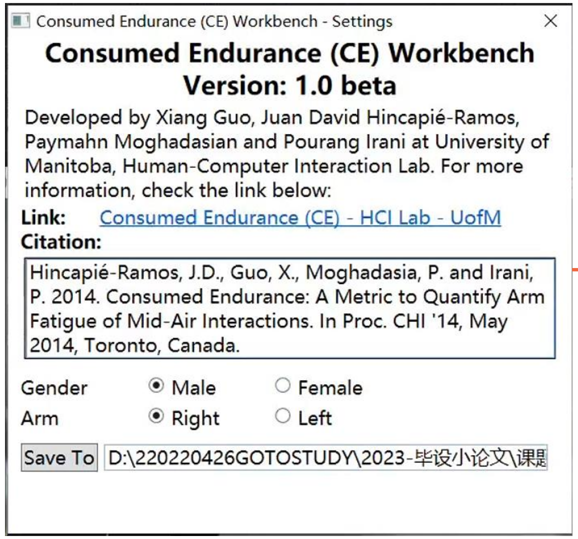
选择主程序后，点击启动。

步骤四

启动后弹出消耗耐力CE评估软件界面

消耗耐力测试实验

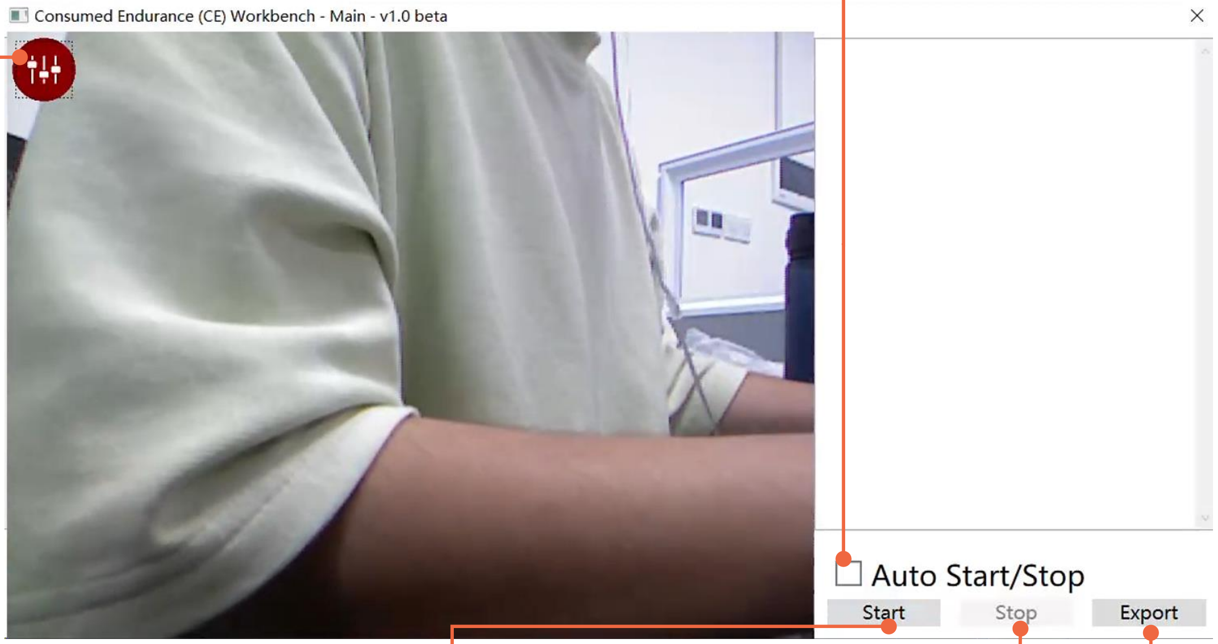
步骤四：消耗耐力测试软件介绍



设置界面

分别设置性别、评估的手臂和数据存储路径

自动开始停止



开始按键

开始消耗耐力评估

停止按键

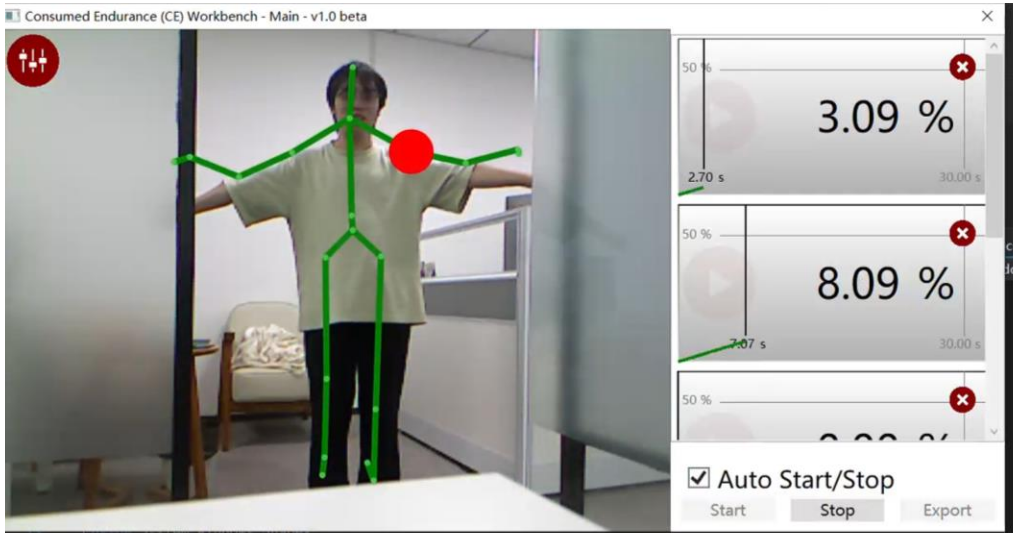
停止消耗耐力评估

导出按键

导出消耗耐力数据

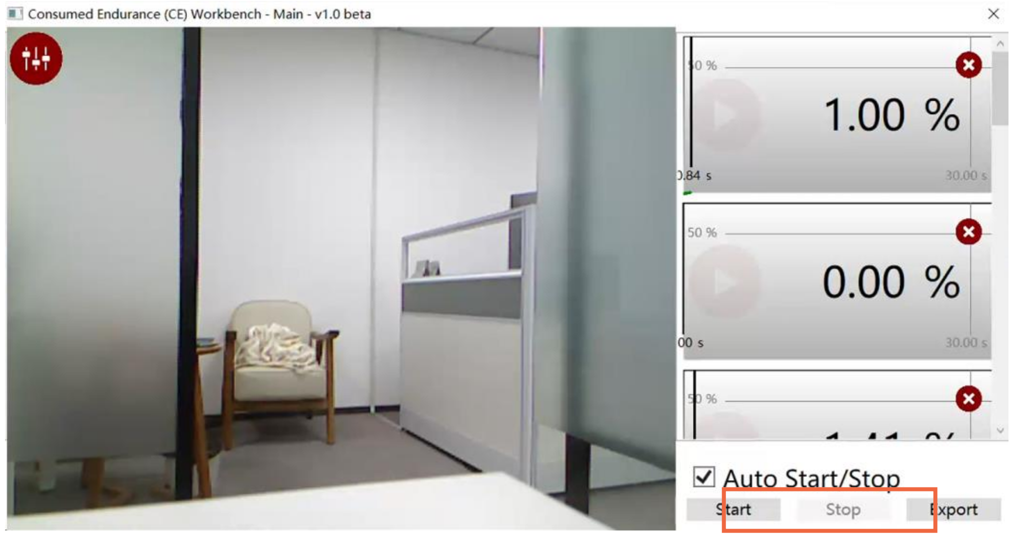
消耗耐力测试实验

步骤五：选择Auto Start/Stop，点击Start



步骤一

此时，Kinect将捕获到被试者的躯干位置，用户的消耗耐力以每10s为单位记录。

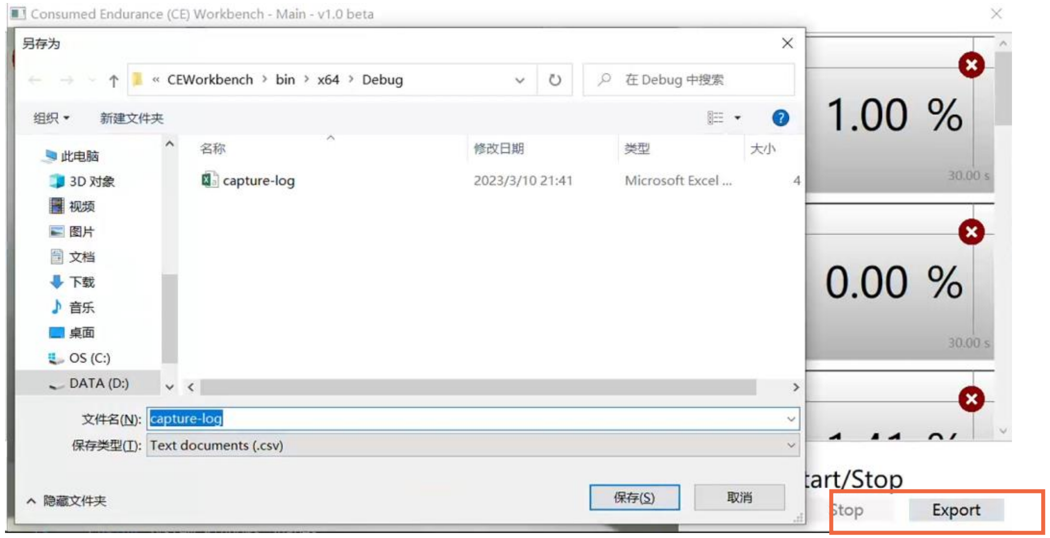


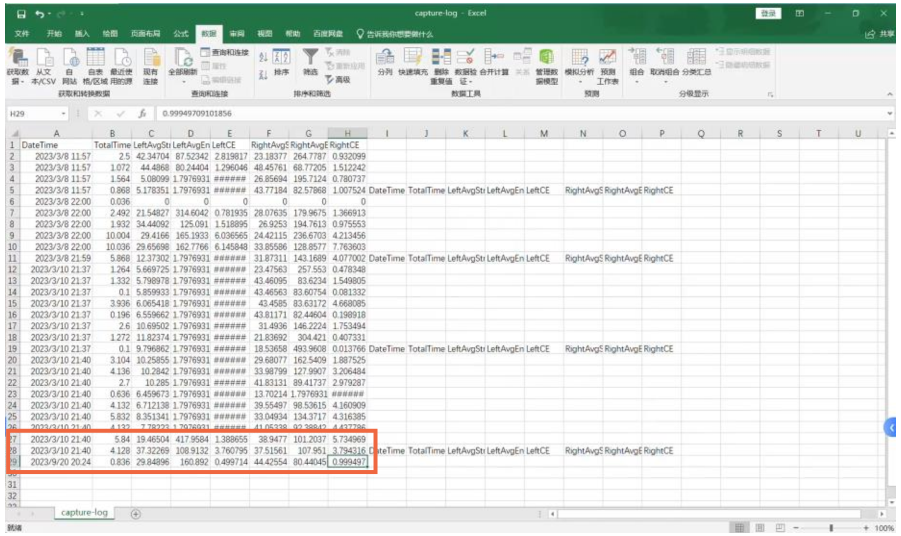
步骤二

点击Stop，停止记录。

消耗耐力测试实验

步骤六：导出数据





步骤一

点击Export，导出数据。

步骤二

打开Excel表格，查看CE值