Co-DesignMR: A MR-based Interactive Workstation Design System Supporting Collaboration

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**Abstract**

Digital prototyping and evaluation using 3D modeling and digital human models are becoming more practical for customizing products to the preference of a user. However, the 3D modeling is less accessible to casual users, and digital human models suffer from insufficient body data and less intuitive illustration on how people use the product or how it accommodates to their body. Recently, VR-supported ‘Do It Yourself’ design has achieved real-time ergonomic evaluation with users themselves by capturing their poses, however, it lacks reliability and quality of design. In this paper, we explore a multi-person interactive design approach that enables designer, user, and even ergonomist to collaborate to achieve the effective and reliable design and prototyping tasks. Mixed Reality that utilizes Hololens and motion tracking devices had been developed to provide instant design feedback and evaluation, and to experience prototyping in physical space. We evaluate the system based on the usability study where casual users, designers are engaged in the interactive process of designing items respect to user’s body, preference, and environment.

**Keywords**: Collaborative design, Human factors, MR, In-situ environment.

**Introduction**

In recent years, digital modeling and prototyping have been burgeoning in the field of industrial design and human-computer interaction (HCI). Computer Aided Design (CAD) tools are typical examples that focus on the virtual modeling of 2D and 3D products. These tools are more utilized by professionals who have mastered the knowledge of creating 3D geometry through the CAD interface. However, some tools are relatively difficult to learn, and special training is needed for familiarization of the interface. Therefore, some researchers have been concentrated on creating novel interfaces using gestures, sketching [1], virtual reality [2], augmented reality [3], and other existing objects [4] as references. On the other hand, CAD digital human models are the other aspects that enable the evaluation of the quality of products. Digital human models are utilized to assess the safety and usability of products and environment in virtual space[5]. Besides, it suffers from the difficulties of accurate prediction of human behaviors due to the lack of human anthropometric data. Most digital human models tend to represent variations of body shapes for the general population, which can be a challenging problem when it comes to customizing products. Now, the question is how to make the product design connected to those people who are not only in the general range but also beyond the general range? One challenge is how to connect a user’s anthropometrics with pose recommendations and design dimensions, which may need a large amount of time to get information on an individual in the usual way. Another challenge is the ergonomic evaluation for casual individuals. Since most of the ergonomic evaluations using digital human models...
have highly relied on the general population, which makes the evaluations to be inapplicable to these minorities. With these challenges ahead, research has been focused on real-time ergonomic evaluations. Recent research endeavors to use sensor tracking devices [6] and wire-free sensor-based device [7] to provide an ergonomic guideline for the individuals. Since these devices support real-time interaction with objects, and they provide a way to get body information through sensors and trackers. Sensors can be integrated into modern computer graphics technology such as Virtual Reality (VR). Thank VR, we have more capability to walk in a virtual 3D world and do whatever want without going to the real physical space. This technology also helps to offer new possibilities when we perform product design [8], design evaluation [9], ergonomic evaluation [10, 11], simulation [12] and manufacturing [13]. It turned out that some VR technologies aiming to design, simulation and manufacturing seem to be mature, but, in order to be more scientific, human-centered VR system of product evaluation still needs a long way to go. The reason why ergonomic evaluation for human-centered systems is difficult is that human varies from one to another and a certain range of body parts cannot represent others. In a VR environment, human bodies are replaced by virtual avatars or zombies, which actually impede the intuitive interaction with the 3D world in the evaluation of human-centered systems. Some research utilizes the body scan and 3D reconstruction to make an avatar for individuals [10], however, it seems to be very cumbersome and time-consuming when we have to scan and reconstruct each by each. On the other hand, some studies try to enable casual users themselves to design and evaluate body postures by themselves [10, 14], in which the method is called Do-It-Yourself (DIY). Although the framework could be good in some way, since they know better what they want, and it could be more convenient for their personal preference, it cannot ensure reliability and quality.

Regarding these challenges and drawbacks, it makes us more conscious about how to make design possible for all body types through a better way or a practical approach? What if we do not need to try to scan the body and make an avatar to make interaction with virtual products? What can we do to overcome the uncertainty and unreliability of DIY? What can we do to make a more instant ergonomic evaluation and design feedback for all types of users? What if prototyping manifests itself in a way that designer, user, and even ergonomist could virtually gather together to accomplish fast prototyping? It seems that Augmented Reality (AR) and Mixed Reality (MR) can help us to perform a design task in physical space and interact with virtual products to accomplish an ergonomic evaluation. Unlike VR, which creates an entirely new and immersive 3D environment, AR and MR add more information to the user’s current environment. Meanwhile, in order to overcome the prejudice of casual users and unreliability of the design through DIY, it would be better if we include designer and ergonomist to the design process. It would better if designer, ergonomist, and the user are all congregated locally or remotely to finish the rapid design and evaluation task, and instant prototyping task is possible using 3D printing.

Design systems for casual users need more concentration on usability study since user-centered interaction design requires more effort to evaluate products by testing them on users [15]. Since casual users are those who don’t usually have common preferences as the general population, and the design should be able to balance the difference the personal prejudice and scientific design guidelines. Therefore, how to make the design system to be available not only for the general public but also on the casual users could be highly relied on the usability study. It should be able to satisfy the expectation of designer and ergonomist as well as they would be able to correctly identify the special requirements and provide a more reliable way to the user-centered design process.

The rest of this paper is organized as follows: Section 2 will introduce some related work and compare the similarities and discrepancies. Then, the proposed framework and methodology will be explained in Section 3. And experiment results of our method will be discussed in Section 4, followed by the discussion and conclusion in Section 5.

**Related Work**

Designing interfaces or systems for modeling 3D objects that are accessible to casual users are of great importance for customization since they enable non-professionals to show their preferences, needs, and expectations, meanwhile, engage themselves in design by themselves or with specialists. As mentioned in [10], it is very crucial to provide people with the capacity to create what they want and make the design fit their geometries. They focus on building the experience prototyping technique initiated in [16]. How to know the pose is good or not should highly rely on ergonomic evaluation [10, 17, 18].

**1.1 Understanding user and pose measuring**

The intention of understanding users is that, in a user-centered approach, they need to model 3D products through design interfaces. In [14], Lee et al. conducted formative and evaluative studies that target on the casual users in the iterative process of personalizing items related to their use, body. In this way, casual users have the chance to determine dimensions using their body posing and acting. In the virtual environment, they can experience their design idea and evaluate their design through the feedback. However, the prototype captures the user’s body pose and supports a referral of a wide range of body parts, which can only be working for some simple boxed based design. For more complex designs, the location and hand gestures and
poses must be captured to support reference plane. The similar work also comes from [24] where Bolt et al. use voice commands to move shapes with matching gestures and [25] where Mignot et al. conducted a research on the integration of continuous speech into multimodal user interfaces, which could be acting as inputs and outputs. They find that multimodal commands are less ambiguous than purely oral and gestural commands.

On the other hand, understanding the user’s pose is also a challenging issue. As we know that human-centered systems are usually connected with active task performance, which in turn indicates that measuring posture and providing feedbacks are a common but crucial problem in most design processes. Some studies focused on using wire-embedded sensors to measure poses [31, 32], others use wireless sensors [33] and augmented mirror [34] to measure poses. Saul et al. in [37] initiated a design system for end users. The system allows end users to draw different styles of chairs and then a virtual human representing the user is placed on the chair to verify the stability of the chair. However, as we mentioned earlier, the virtual or digital human model cannot represent the real human body and the anthropometric information is limited due to a shortage of data. Therefore, in this research, we claim that using the real human body for evaluation should be the better and more reliable approach for end-users. In summary, these studies strive to help users to understand and retain comfortable poses in their work, however, they fail to take the work environment into account, which could be problematic when their poses are disjointed with their work circumstances.

1.2 Ergonomic evaluation in design

Ergonomic evaluation is extremely crucial part of the design. In the past decades, ergonomists heavily relied on the 2D drawing on human anthropometry to show whether the body height fits the products or not. Especially for human-centered product design, the optimal work environment for certain tasks needs to be constructed so that any long-term or uncomfortable postures could be avoided. Since ergonomic assessments assist in preventing uncomfortable postures and some work-related injuries. Many textbooks provide lots of background knowledge about ergonomics through practical design guidelines [26, 27, 28, 29]. Some studies show that ergonomic knowledge could be beneficial to the users when they change their body poses to adjust to the workstation and shift their work styles effectively [30]. It is obvious that 2D drawings cannot meet the requirement of personal prototyping. With this issue, some offline 3D ergonomic assessments were carried out in the ergonomics field. The most typical representative is using digital human models. In [23], Woldstad et al. CAD human models used to design both equipment and work environments to meet human operations. Through the use of digital human models, designers and ergonomists can position and manipulate operator with different anthropometry within the simulated work environment. In [19], Mochimaru tries to target people with special and embed digital human models to support design workshop. However, digital human models suffer from insufficient anthropometric and strength data, and the accuracy of prediction still needs to be improved to reach the goal of accurate prediction. In recent years, some real-time ergonomic assessment methods have provided a great platform for the design process. In [17], Haggag et al. use Kinect sensor as a platform to support real-time rapid upper limb assessment (RULA) for assembly operations in industrial environments. They use voxel-based angle estimation to calculate angles of each joint of the upper body part. However, the joint occlusion makes the estimation unstable, and hand tracking is not supported in the current sensor, which impedes the arm assessment. In [18], Pastura et al. developed a computational system for joint angles calculation of human body, they use tracking markers positioned on specific anatomical points of the body to design define body segments. Through the AR environment, they build a low-cost infrastructure, which is comprised of webcam and paper makers to compute joint angles. Lee et al. in [11] then visualize the ergonomic guideline for furniture design. They explore the application of ergonomic guidelines in personal fabrication and identify a dependency map between the user’s anthropometrics, ergonomic pose recommendations, and design dimensions. However, the angels of body parts are partially displayed and only some static posture can be captured when the designer drag the human avatar to evaluate poses. In this research, we meditate on providing intuitive ergonomic evaluation and instant design prototyping based on user’s on-site performance of tasks.

1.3 Collaboration design system and VR/AR

In recent years, VR application with HMD devices has facilitated the design of virtual objects with real-scale and immersive environment. Lots of research focus more on virtual modeling and sketching. In [34], Yee et al. proposed a method to do in-situ 3D sketching in the augmented environment. Gjosater et al. in [35] presented research called ‘FurnitureAR’, which applied augmented reality to collaborative furniture design. They highlighted the idea of collaboration among designers who can first sketch design ideas in the CAD program and load model to FurnitAR for collaboration. In the collaborative environment, the CAD model can be freely modified by designers and, meanwhile, the usability factors can also be determined. However, they did not consider the ergonomic evaluation of the design model since the furniture may not fit users or cause discomfort. In this paper, we argue that human-centered design with a group of professionals and non-professionals is much more reliable and efficient than one casual user or designers themselves. The first collaborative design
framework with ergonomists was initiated by Pontonnier et al. in [20]. They proposed to use a VR-based immersive virtual environment to represent workstation. They suggest to compute and visualize biomechanical factors that could be represented as virtual manikin or simple curves to ergonomist. The basic idea of the framework is to user sensor-bridging and sensor-sharing information to enhance the user’s cognition and comprehension of the task. However, this idea was just considered as a potential application of the VR-supported prototyping of the workstation design. Their proposal can provide us the indication for collaborative design with professionals and end users. However, VR based collaboration has one problem is an avatar. Since in the virtual environment, the human body can only be represented through the utilization of digital models, which also have the demerits similar to what we mentioned in former sections.

In [21], Noh et al. propose an MR system for avatar-mediated remote collaboration. They present an application that enables a local user to interact and collaborate with another user from remote space using natural hand motion. The system summons the remote user to the local space, which is displayed as a virtual avatar in the real world view seen by the user. This idea is somehow comparable to what we propose to our design system. We claim that user-centered design is not reliable than collaboration. In this paper, we focus on collaboration with a real-time ergonomic assessment to facilitate the design task for casual users. We are trying to overcome difficulties that the previous design systems have and use a more robust way to provide casual users as a main-operator of the design task.

| Table 1 A comparison of several representative research. |
|---------------------------------------------------------|
| **Research focus** | Vilas et al. 2012 | Lee et al. 2018 | Taylor et al. 2013 | Pontonnier et al. 2013 | Saul et al. 2011 | This research |
| H/W | Kinect/HMD | Kinect/HMD | Kinect | Mocap + EMG | Webcam Markers | Hololens + motion tracker |
| S/W | N/A | Unity | N/A | N/A | NyARToolkit | Unity |
| Aimed for all users | No | Yes | N/A | N/A | N/A | Yes |
| Augmented collaboration | No | No | No | No | No | Yes |
| Real-time ergonomic evaluation | N/A | Yes | Yes | N/A | No | Yes |
| Active pose measuring | No | No | Yes | No | No | Yes |
| Interactive simulation in design | Yes | Yes | No | No | Yes | Yes |
| Evaluation of system | Yes | Yes | No | No | Yes | Yes |

**ERGONOMIC GUIDELINES FOR PERSONAL FIT**

For this initiative research, our optimal goal is to develop a system that can be used to design of most types of human-centered products. However, from the idea verification stage, we do not want to delve into too broad system concept, therefore, in this paper, we shrink our concentration and choose one special human-centered
design topic, which is office workstation design. From the data source of Australia [38], from 2015 to 2016, around 60% of people working in office suffer from musculoskeletal disorders. As shown in Fig.2, the designer needs to take care of the design the workstation that should be able to prevent any repetitive strain injury, eye strain, fatigue, and discomfort. We could speculate how important it is to include ergonomist in the design process so that they can incorporate some guidelines for avoiding any discomfort. Nowadays, most of the work is heavily computer-based, so most people fall into the category of moderate to heavy computer use [22]. Unstable desk layouts cause many awkward poses, which further lead to severe pains and aches. We can see the great impact of improperly designed office workstation on the well-being of a human body, which indicates that ergonomic evaluation for individuals could be playing a more important role in the design. Even for casual users, it is critical, therefore, that the computer workstation to be designed accordingly to good ergonomic standards.

One problem about general ergonomic guidelines for office workstation design is that they are most fit to the large percentage of an intended user population, and are confined with a range from 5 percentile to 95 percentile. On the other hand, as mentioned in [11], the guidelines for ergonomists are based on the observation of body poses and angles to evaluate design quality, however, these guidelines are not directly aimed for individuals and for providing reliable design recommendations. As they have divided the guidelines into body-centered guidelines, object-centered guidelines and space-centered guidelines, which could be seen from Fig.1. Body clearance indicates the distance between body and desk, body reachability indicates the limitations of our hands and arms. They also modified the guideline from the general population to a person. The elbow angle for sitting posture is explained between 70 to 100 degrees. In this paper, we consider using this person-oriented ergonomic guideline for design evaluation and decision-making.

![Fig.2 we adopted the ergonomic guidelines from Lee et al. 2018 [11].](image)

**PROPOSED METHOD AND DESIGN CONSIDERATION**

In this section, we propose our methodological that could backbone the initiative collaborative design work. There some basic challenges to be solved for our system. First of all, we try to overcome the drawbacks of capturing the human body to make a virtual avatar in [11]. Since it takes too much time and energy to scan the body and make an avatar, so we propose a new way to track the human motion of a real human in AR environment, without avataring user in local space. Second, we acknowledge DIY is good for some cases, however, it needs to be verified and studied more afterward. we instead stress on the group design where the system should summon designer and ergonomists from either local space or remote space to have collaboration with users to accomplish an efficient and reliable design. Third, we aim to create some more intuitive and situated experience in the design guidelines. Previous research focus on simple box-based design, however, we aim to create more complex designs by using hand gestures, poses, and locations in AR environment. Last but not least, we make efforts to create a platform for designer and ergonomist who are in the remote place to participate in the authentic ergonomic evaluations and design. It can also enable them to have a more intuitive ergonomic evaluation if they are in the local space. As mentioned in the last section, we develop situated and interactive guidelines to assist users in design applications. Based on the ergonomic design guideline,
we try to develop the situated and interactive guidelines to assist designer, ergonomist, and user to conduct collaboration work in the design application. We try to develop the MR system that enables user, design, and ergonomist to join the customization of workstation, and the system can provide real-time feedback and recommendations to the design and pose. As shown in Fig.3, we put the user in the center place, where we first study the needs of users. The user cases are concentrated in order to establish design guidelines. We first find the gap of designing for the general population and designing for minorities. As most users are suffering from various pains (e.g. neck pain, musculoskeletal disorders, etc), which is more or less indicating that there might be improper design problems. Since designer-centered workstation prototype cannot satiate the requirement of all users, we aim to make the design approachable to all users whether they are tall or short, fat or thin, young or old. We are trying to specially take care of minorities and make design guidelines for the convenience of designers. Based on the guidelines and needs, we design our system that enables designers to make human-centered workstation prototypes and provides users with various solutions. For workstation design, there will be many kinds of types, either for sitting or for standing. Thus, we strive to make the system possible for designers to show the digital prototypes and test on the users while listening to the requirements of users. Meanwhile, we also focus on the evaluation of ergonomists who will provide a more robust analysis of the design and provide more scientific feedbacks based on the pose study and estimations. Therefore, we insist on the collaboration with ergonomists to ensure that both users and designers can have more reliable interaction through the feedbacks from an ergonomist. On the other hand, except intervention of improper design, one reason why we focus more on ergonomists is that they try to deepen observation on poses and make decisions with designers to ensure the product or prototypes to be comfortable and safe.

We highlight two design considerations for our system, namely, information sharing, multi-user interaction, and spatial engagement.

![Fig.3 Information workflow of collaboration system.](image)

**Information sharing**
The guidelines and workstation dimensions can be provided in different ways. In this research, we focus on visualizing them in augmented space. The ergonomic postures and angles from back, neck, and elbow are visualized as a way similar to the ergonomic textbook, such as in [27, 28]. We visualize the angle range on a real person in an AR environment and the dimensions (height, width, length, etc.) of virtual workstation that is connected to physical ground, as shown Fig.6. Besides, upper body angles are highlighted when the angles are beyond the range of recommendations. We try to make the workstation design a process that includes information gathering, and information collected, especially the user’s preference and pose, will be shared among all participants.

**Multi-user interaction**
As the design is conducted among user, designer, and ergonomist, meanwhile, design guidelines are associated with user’s body, pose and preference, therefore, the system needs to provide communication and interaction between the user, designer, and ergonomist. For instance, when the user says they want to fix certain desk height after adjustments, the designer needs to get feedback from the user and observe user’s body and workstation
dimensions to make sure that they are in the allowed ranges or sizes.
Meanwhile, the ergonomist and designer need to provide feedforward and feedback to each other when the user performs tasks. For the ergonomist and user, they also need to have real-time interaction. For example, when users say that they are content with the workstation design, the ergonomist has to check several representative poses and make sure that the ergonomic evaluation is reasonable and reliable. This idea is making the interaction flows not only between human and computer but also human and human.

**Spatial engagement**
One crucial aspect for the collaborative design and evaluation system is that it needs to support immersive feedback to user and designer so that designer can modify the dimensions in the system. Meanwhile, the ergonomist also provides some control through gesture and voice. For example, when the user’s pose is not good enough ergonomically, so he will provide gesture control in the 3D user interface so that the user will follow the guidance to adjust his body pose. This iterative process will go through several steps, and it will terminate when three people have consented. The design system will largely both user be aware of his pose and ergonomic knowledge, and be able to design for their bodies and needs.

**SYSTEM design**
The system consists of three modules as shown in Fig.4. Basically, the MR-supported design system includes the local augmented space when the user is in the augmented space, he can virtually see the augmented workstation, designer and ergonomist. When he performs a task that is required by the designer and ergonomist, there will be instant feedback shown in the user’s body, where his ergonomic information is automatically displayed in the AR space, and data is even set to ergonomicist. When there are some abnormal poses happening in the user’s space, the system will give warning to ergonomicist, he will give environment where all people involved can be fully engaged. One challenge might be the case where user cannot see the virtual scene clearly due to the narrow field of view of Hololens. Therefore, the system must ensure that all information in Fig.3 can be shown in the augmented space, and all participants could be able to fully engaged in the design process. If all necessary design parameters and related anthropometrics and ergonomic recommendations are not apparently shown, either user or design will lose concentration, which could demolish the validity of design and evaluation. In order to verify the effectiveness of the design system, the spatial engagement could be one of the checking points.

![Fig.4 Interaction scenario of our collaborative system.](image)

Fig.5 depicts the detailed methodology of our system. The prototype was built in Unity 3D as a platform for generating an AR environment. We created two types of workstation for a designer, which are somehow simplified but similar to the real one. A virtual computer with keyboard and mouse was placed in the desk so that it provides the user with the chance to be fully immersed.
when performing tasks. The system consists of three functions. First of all, in order to conduct an ergonomic evaluation, we use Microsoft Kinect for Windows to be the motion and pose capture device, which is aimed to track body joints and conduct angle calculation, especially for upper body (see Fig.5). The joints were used for ergonomic measurements, for projecting skeleton of users to AR space generated in Hololens. Second, calibration using Vuforia markers. The calibration was done through a virtual box created in AR space and was based on the affine transformation matrix calculated from quaternions. The measured angles include viewpoint angles from eyes, arm angles, trunk flexion angle, and lower arm flexion angle. Meanwhile, the distance of desk layer to ground and workstation dimensions are shown in both the user’s view and the designer’s view. Lastly, the two Microsoft Hololens is used for collaboration in the AR space.

The ergonomic body pose evaluation was assessed in Hololens space, where the projected Kinect body joints and measured angles are shown in the user’s body, and meanwhile, the virtual desk is displayed in front of the user. The sharing of Hololens scenes is conveyed through a server, which connects other Hololens through WiFi. The collaborative design system aims to personalize workstation design with ergonomic guidelines through the incorporation with anthropometrics, pose and design dimensions through sharing in AR space. The system only focuses on the interaction between human and computer but also the interaction between human and human in augmented space.

Fig.5 (a) Vuforia marker for calibration and (b) tracked body skeleton by Kinect.
**USER STUDY: SYSTEM EVALUATION**

In order to evaluate our system, we conducted user-study and tried to get some feedback from participants about how they think of the virtual and imaginary digital prototypes. We were interested in how well they feel about the non-specialists could collaborate with the designers and to what extent they could feel the augmented workstation when performing tasks. During the study, we collected preliminary qualitative feedback to gain insight into the experience of collaborating with the designer.

We recruited 5 participants between the ages of 25 to 28 (M: 26.4, SD=1.64) to do a preliminary evaluation of our system. The participants were first asked to listen to our introduction to the tasks and system principles. We started by introducing why do this, what they can see from Hololens and what they will be doing in the augmented environment. As shown in the following Fig.7, one subject is designing the workstation with the designer in augmented space.

**Results and discussion**

After the user testing, we did the questionnaire survey. The first question we asked was “how clear can you feel the existence of computer workstation in Hololens space?”. 4 people replied that the existence is clear and only one participant said the view was small so she can not actually clearly see the workstation.
In the following question “to what extent can you be absorbed in performing the task on the virtual desk”, we asked them about their concentration when performing the design tasks. 80% percent of participants replied that they are immersed when performing design tasks.

We were quite content with the engagement with the designer.

In question 3, we asked to what extent they felt engaged during the collaboration with the designer in certain scenarios. Most percent of participants replied that they were quite content with the engagement with the designer.

We then evaluated their convince about their pose when they said they were sitting in a proper way or sitting correctly. 60% of the participants said that they were sure their poses were good for them when they finalized their expected workstation dimensions done by the designer.

In question 5, we asked them about their satisfaction with the design made by the designer. 60 % of people gave a good feedback about the design done by the designer. The other two participants said that they were not sure about the design quality due to the small field of view (FOV) of Hololens.

Lastly, we provided that chance for them to give any suggestions to the design of our system. Most people said the design is fabulous, however, the vision of Hololens is too narrow, which mitigates the quality of experience in the experiment. They all wanted to get a wider view for better immersion in the augmented space.

**Conclusion**

In this paper, we have presented Co-DesignMR- a mixed reality environment for workstation design through collaboration. We described the problems of previous studies, the current needs for reliable digital prototyping, and the implementation details. The system was evaluated in the experiment showing that users and the designer can successfully conduct collaborative design based on ergonomic evaluations. We have proposed a set of system method and proved it through the demonstration to finalize workstation design between users and designers. In this application, we only have two Hololens, which impedes our highlight on getting more robust feedback from professional ergonomists. However, it turned out that the system could perform well on some users. In the near future, we will add one more Hololens for ergonomist to join the collaboration and, meanwhile, add more ergonomic information to the augmented space. Besides, we are aiming to generalize the workstation design to other human-centered product design.

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