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研究課題名（英文）Gaze understanding in Optical-see-through Head-mounted Displays

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研究成果の概要（和文）：我々は光学透過型ヘッドマウントディスプレイ(以下，OST-HMD)装着時，ユーザの焦点距離を推定するシステムを開発した．さらに，OST-HMD上に描画された仮装物体の現実感を高めるために，推定された注視距離を利用するいくつかのシステムを開発した．さらに我々はOST-HMDの設計上の制約を解消するために視線追跡手法を適用し，ユーザの視点からみたOST-HMDフレーム上の遮蔽物体を検出し，強調表示するシステムを開発した．加えて，瞳孔径からOST-HMDに表示される仮装物体の最適輝度推定システムも開発し，これがユーザに好まれることも明らかにした．

研究成果の学術的意義や社会的意義
本課題の研究成果から，OST-HMDのユーザインタフェース設計時には，ユーザ固有のパラメータが重要な役割を果たすことが明らかとなった．また，この知見は，ユーザインタフェース設計における視線計測の将来的な応用に関する一連の新たな質問を投げかけている．加えて，我々のシステムにより，OST-HMD使用時の安全性やユーザの快適性を改善することができ，ひいてはそれがシステム使用時のユーザの不快感を減少させ，長期使用時の満足度を改善できる可能性が示唆された．

研究成果の概要（英文）：We have developed a system that estimates the user's focus distance when wearing an Optical See-Through Head-Mounted Display (OST-HMD). Our system was able to distinguish between different distances the user focuses on. We then developed several systems that utilized the estimated focus distance to improve the realism of virtual content rendered on the OST-HMD. Our results show that although we could improve the realism and legibility of the virtual content, user-specific variances played an important role in the perceived quality.

We also applied eye tracking to overcome limitations in the design of OST-HMDs. We developed a system that detects content that is occluded by the frame of the OST-HMD from the user's view and highlights this information to the user. We have also developed a system that can estimate the ideal brightness of virtual content shown on an OST-HMD from the user's pupil size. Our adaptive brightness adjustment system was preferred by participants.

研究分野：拡張現実感

キーワード：ウェアラブル機器

１．研究開始当初の背景

Optical see-through head-mounted displays (OST-HMDs) are likely to become the natural extension of, or replace mobile phones as the interaction medium in the near future. In OST-HMDs graphics get projected into the user’s field of view. Users can see the virtual content and real world at the same time. This is a major benefit of OST-HMDs over handheld devices. It frees up the user’s hands to interact with their environment; presenting information only visible to the user, thus increasing the safety when handling sensitive information; and naturally providing virtual information registered to the environment, thus reducing the mental load needed to process it. As such, it is no surprise that a number of leading manufacturers and information technology companies have either announced or released new OST-HMDs in recent years.

Nonetheless, OST-HMDs still suffer from a series of deficits; e.g., limited computing power, short battery life, small field of view, unstable tracking and localization, and spatially inconsistent rendering, to name a few. The recently released Microsoft HoloLens tackles a number of these problems, but it also lacks eye-gaze tracking (EGT) capabilities.

Past research has shown that eye-pose and eye-gaze estimation could greatly benefit OST-HMD. It has been applied for calibration of OST-HMDs, content adjustment, user vision correction, interaction, content correction, or visualization adjustment. Previous methods are conceptual and assume that in the future it will be possible to accurately track the user’s gaze regardless of the depth the user is focusing on. Current EGT methods achieve accurate gaze estimation only close to a pre-defined depth plane and can distinguish only a few focused depths. This research focused on the development of techniques that can estimate the depth the user is focusing on and apply this to create intelligent user interfaces for OST-HMD.

２．研究の目的

Although eye gaze has often been envisioned in Human-Computer Interaction, it usually only investigates the interaction with 2D content. On the other hand, an OST-HMDs presents virtual content in 3D. This raises the need to be able to estimate and track the user’s gaze in 3D. This includes estimating the depth of an object a user is focused, e.g., to determine what object the user is focused on when multiple objects overlap each other, or when users are trying to observe the real scene that is occluded by computer graphics (CG) rendered on the OST-HMD screen. As most systems focus on gaze estimation in a single plane, which is viable for desktop machines, the tracking accuracy degrades when users observe content over a 3D volume. It is necessary to improve this estimation to enable interaction with virtual content in crowded scenes, and to prevent inaccurate depth estimation.

Furthermore, we need to consider how the estimated eye gaze location can be applied to improve the user experience when interacting with content shown on an OST-HMD. Although many active selection and gaze-aware interfaces have been considered for desktop systems [1], OST-HMDs present additional challenges like overlapping CG and real world, transparency, and the fixed focal plane of the OST-HMD screen to name a few. User interfaces that react to eye tracking can make the interaction with computer graphics more intuitive, natural, and realistic. Therefore, it is also necessary to investigate how eye tracking can be applied to improve rendering of and interaction with content presented on an OST-HMD.

To summarize, our goals for this project were to:

- Investigate how the depth a user focuses on can be estimated from eye tracking information.
- Investigate how user eye gaze can be tracked in different focus planes.
- Determine how eye tracking information can be used to improve rendering of and interaction with virtual content.

３．研究の方法

To achieve the goals of this project we addressed three work packages:

(1): Depth Estimation
(2): Gaze-Adaptive Rendering
(3): Intelligent User Interfaces

During the first year we focused on all work packages. In (1) developed a method that estimated the user’s focus distance from the estimated gaze direction. We evaluated how accurately the system could estimate the user’s gaze for different distances and also for distances where no observations were collected beforehand.

In (2) we developed two algorithms that address rendering limitations of virtual content on an OST-HMD. In the first project we focused on improvement of SharpView [2], an algorithm previously developed at our laboratory. In many applications, e.g., when the virtual content annotates the scene, users need to view the real scene and virtual content in focus. However, as the virtual content is rendered at a different focal plane from the real world, users will perceive the virtual content as being blurred. SharpView predicts the blur users see when observing real and virtual content at the same time. By sharpening the viewed content the system can counteract the naturally observed blur by user. In this experiment, we investigated how user preferences affected the results of our algorithm to determine whether a user-specific model is necessary.

In a second project, we developed EyeAR, a method that replicated naturally observed depth of field (DoF) effects for CG viewed on an OST-HMD. By measuring the user’s focus distance we replicated the DoF effects users would observe when looking at real objects at the same distance as the virtual content. The goal was to determine whether we can replicate realistic refocusing of virtual content without multi-focal displays.

During the first year, (3) focused on the development of a method to adapt the observed brightness of the scene by considering perceptual properties of users. We created BrightView, a novel OST-HMD system that consisted of an off-the-shelf OST-HMD with a liquid crystal (LD) shutters attached to it. By gradually adjusting the transmission rate of the LC shutter, we adjusted how brightly users perceived the surroundings. At the same time, as the LC shutter did not affect the brightness of the virtual content, we expected this to result in users perceiving the virtual content to be brighter. Furthermore, by gradually adjusting the transmission rate of the LCD shutter we suspected that we can reduce the perceived darkening of the surroundings due to light adaptation.

During the second year, this project focused on designing additional intelligent user interfaces for (3). We extended our work from the first year, to design IntelliPupil, a method that accounts for the brightness of the background which the virtual content is overlaid onto to automatically adjust the brightness of the virtual content to achieve a consistent pleasing experience. We first collected observations of the user’s pupil size in different brightness conditions and user preferences for brightness of different virtual content in these conditions. We then trained a neural network that predicts the ideal brightness of the virtual content. Hereby, we utilize information about the displayed virtual content, the background brightness, and the user’s pupil size as the input of the network.

Finally, we have addressed limitations users face when wearing an OST-HMD. In particular, we focused on the occlusion of the user’s field of view by the OST-HMD frame. By predicting the user’s natural view and areas occluded by the frame of the OST-HMD we devised to methods that notify users of detected movement in the occluded portions of his view. The first method presented users with indications in the center of the OST-HMD thus ensuring their visibility, but potentially distracting the user from the task at hand. The second method utilized our sensibility to brightness changes in peripheral vision. By activating LEDs attached to the frame of the HMD, the system attracted the user’s attention into the direction of detected movement.

４．研究成果

The results of our work show that user-specific parameters play an important role when designing user interfaces for OST-HMDs. In (1) we found that while our system could accurately predict the gaze distance for some users, for others we observed large errors in the estimated gaze distance. Similarly, our experiments in (2) showed that user specific preferences played a major role in the degree of sharpening participants preferred. Furthermore, although our DoF algorithm could successfully replicate the appearance of real objects and fooled some participants into mistaking them for real objects, we did not achieve this for all tested scenarios.

We have also observed similar results in the projects developed in (3). First, we showed that BrightView was successful in reducing the perceived darkening of the environment while increasing the perceived brightness of the virtual content for simple scenarios. Furthermore, we found that brightness adjustment with IntelliPupil was preferred over a fixed brightness setting. In both systems we nevertheless observed user specific differences. Finally, although we showed that our alertness system we could detect and warn users about movement in the occluded area of their field of view, when we evaluated the system with 3 participants, the opinions of the participants about which visualization they prefer were very different.

The results of our research show that gaze-aware interfaces and design considerations can significantly improve the user experience when using OST-HMDs. Furthermore, we showed that considering user-specific preferences and models plays an important factor when designing algorithms and user interfaces on OST-HMDs. Our findings open a series of new questions, such as how to design interfaces that adapt to user preferences while maintaining a general character, how to further improve the estimation of the user’s gaze in OST-HMDs, and what other properties of our sensory system can be utilized to create attentive and intuitive interfaces.

Our findings can be utilized in the design of future OST-HMDs to overcome some of their limitations to reduce the hurdle of their usability and acceptability. They can also be applied to create devices that target specific population groups, such as elderly, or patients with vision deficiencies.

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５．主な発表論文等

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〔その他〕
ホームページ等
http://imd.naist.jp