3D Digital Prototyping of Information Appliances based on Mixed Reality with Markerless Tracking

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***Abstract*— This paper proposes a mixed reality based digital prototyping environment aiming for user interface (UI) design of handheld information appliances with markerless tracking. The edge-based robust tracking of the 3D housing model was realized. The tracker was integrated with our XAML-based 3D digital prototyping tool of UI design. The accuracies of the tracking were examined, and the user performance measures using the mixed reality based prototyping were evaluated. The results showed higher reality and better correlation with the real product of the proposed prototype over conventional digital prototypes.**

***Keywords*— digital prototyping, usability, user interface, mixed reality, ergonomics, tracking**

I. Introduction

Usability-conscious design in the early design stage has become indispensable for strengthening market competitiveness of commoditized information appliances such as digital cameras. Current usability assessments of these appliances are still dependant on user tests where general users have to be involved. However, expensive physical prototypes whose user interfaces (UIs) can work must be made for the tests, and they are available only in the late design stage.

To solve this problem, commercial 2D digital prototyping tools of UIs design have already been introduced to actual UI design[1], and 3D digital prototyping tools have also been studied recently[2,3]. However, the digital prototypes do not materialize physical housings and UIs, such as switches, and operational reality and user performance indices, might be degraded when they are used in user tests of handheld appliances.

On the other hand, mixed reality-based digital prototyping of UIs for handheld appliance design has recently been investigated wherein an image of a physical housing is captured and a virtual UI image is superimposed onto the image. This approach allows the user to interact with the UI on the prototype in a natural way while avoiding fabricating a physical "working" prototype. In most of the AR-based researches, they used video tracking with markers to sense the 3D pose of the housing held by the user, and relatively large markers need to be attached to the housing surfaces [4]-[6]. However, the tracking fails when an even small portion of the marker is hidden by the user's hand or fingers. This tracking

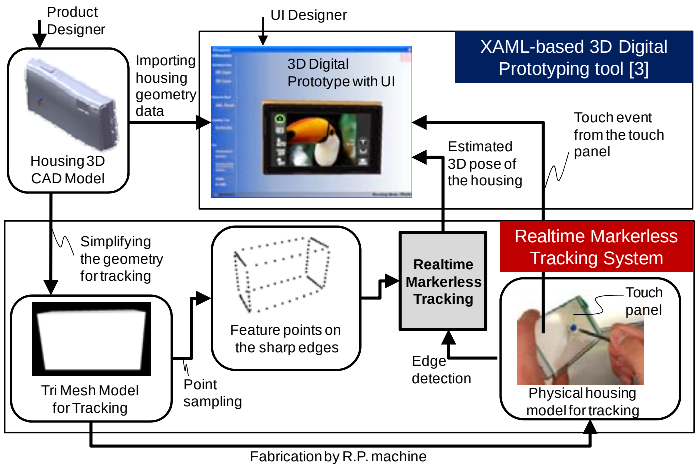

Fig. 1 A mixed reality based prototyping system

instability becomes a serious weakness of the mixed reality based prototyping of up-to-date information appliances with large touch sensitive device on the housing.

Therefore, this paper proposes a mixed reality based digital prototyping environment for UI design of handheld information appliances with markerless tracking ability. The edge-based robust tracking of the 3D housing model was realized. This markerless tracking was integrated with the XAML-based 3D digital prototyping tool of UI design we developed[3]. The principle and accuracies of the tracking method were examined, and the user performance measures using the mixed reality based prototyping were evaluated.

II. Digital Prototyping Environment with Markerless Tracking

Fig.1 shows an overview of the proposed mixed reality based prototyping environment. A realtime markerless tracking system and XAML-based 3D digital prototyping tool[3] are integrated in the environment. The original 3D CAD model of an appliance's housing is modelled by a product designer. Then, a triangle mesh model for tracking, whose shape simplifies the CAD model, is modelled manually, and a physical housing for tracking is also fabricated from the mesh model using a rapid prototyping machine. A video image of the physical housing which a user is holding is captured, and the mesh model tracks and follows the 3D pose of the physical housing using the proposed markerless

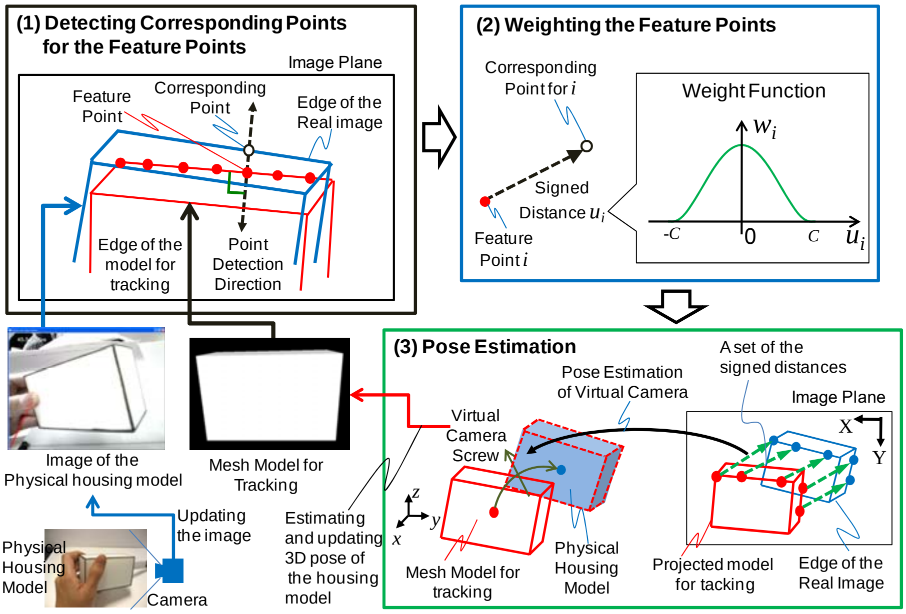

Fig. 2 The markerless tracking process

tracking method. The tracked pose is also transmitted to the 3D digital prototyping tool and a 3D image of the UI is superimposed on the physical housing image.

Moreover, a thin small touch panel is stuck to the UI surface on the housing, and a touch event from the user's finger can be sensed by the digital prototyping tool. This allows the user to physically interact with the virtual touch panel modelled on the digital prototype.

III. Markerless Tracking Method

Fig.2 shows the markerless tracking method used in the environment. The method is a kind of edge-based tracking and is an improved version of Comport's one[7]. Their edge-based tracking method sometimes failed to track box-like objects. We made their tracking more robust so as to keep tracking even for box-like objects.

The tracking basically consists of the three following parts (*A*-*C*):

A. Detecting the corresponding points for the feature points

3D feature points are sampled and placed on every sharp edges of the mesh model before tracking. In the tracking phase, the points corresponding to the feature points are detected from the edges on the image of the housing. If an edge is detected on the image within limits along the normal direction of the sharp edge of the model, then the intersection is set to be the corresponding point.

B. Weighting the feature points

A signed distance, u_i , between a feature point, i, and the corresponding point is evaluated, and a weight, w_i , indicating the reliability is assigned to the feature point i. In the previous method[7], they assumed that the distances haves a Gaussian distribution and the weight, w_i , was allocated based on it. However, from our observation, the actual distribution is far

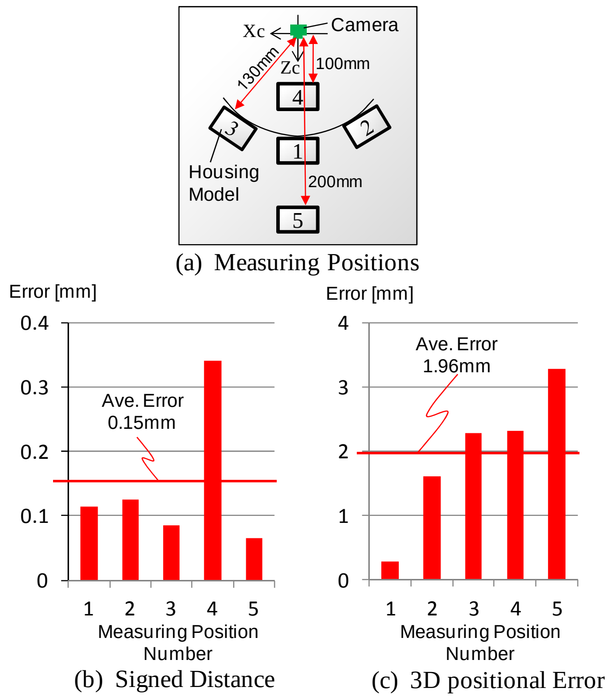

Fig. 3 Tracking accuracy

from the Gaussian one, and very small weights have been allocated to most of the feature points, which caused the tracking to be inaccurate and unstable. Therefore, we re-examined and improved the weight setting so that enough number of feature points can be contributed to the pose estimation and the system can keep tracking even when large portions of the edges are occluded by fingers.

C. Pose estimation

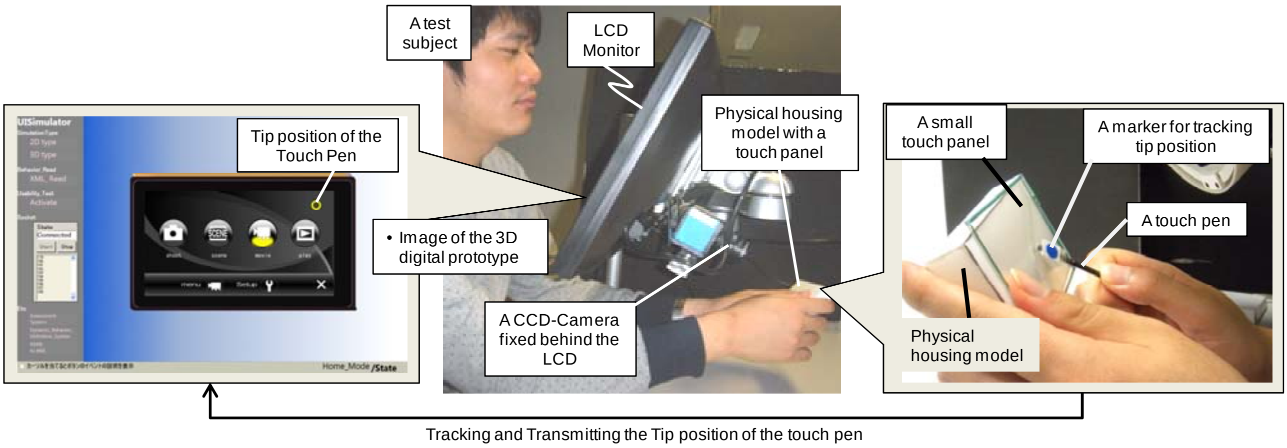

Fig. 4 The prototyping environment setting for the user test

Taking the weights, w_i , for the feature points estimated in *B*, a virtual camera screw consisting of 3D velocity and angular velocity are estimated so as to make a set of the signed distances zero. This screw is multiplied by a current 3D transformation matrix of the virtual camera, and finally the estimated 3D pose of the physical housing model is derived as its inverse matrix and is updated.

Currently, the tracking process is implemented using Open-CV and DirectShow. The tracking speed ranges between 25 and 30fps when capturing an image of 1024x768 resolutions.

The tracking accuracy was also examined. The averaged signed distance on the image during the tracking and the averaged 3D positional error of the mesh model in virtual space with respect to the physical housing in real space were evaluated. A real pose of the physical housing was verified by ISOTRACK. The results are shown in Fig.3. The averaged signed distance was 0.15mm on the image and the averaged 3D positional error was 1.96mm.

Moreover, from our experiments, even when up to 30% of the visible edges were hidden by a user's fingers, the system could keep tracking normally. The robustness enables the user to hold and directly operate the UI with a large touch panel superimposed on the housing by user's fingers without any stress.

IV. Application of the Proposed Prototype to a User Test

The proposed prototyping environment was applied to a user test. A compact camera (Nikon-Coolpix S60) which has a touch panel behind the housing was targeted for the test. As shown in Fig.1, a precise 3D-CAD model of the camera was created, and its simplified mesh model having a rectangular parallelepiped shape was also modelled. The precise UI behaviour of the camera was reverse-engineered and described using XAML, and integrated with the 3D-CAD model.

As shown in Fig.4, the physical housing model made of white ABS-like resign was fabricated using FDS-type rapid prototyping. A flat 3.8inch touch panel was stuck behind the housing. A user can input a touch event on the panel using a touch pen. The tip position of the pen is tracked and displayed on the virtual UI.

A same user task was imposed to 11 subjects where they were asked to switch "*default menu mode*" to "*video capture mode*." The operation time to complete the task and three subjective ratings were compared among the proposed mixed-reality based prototype, a 3D digital prototype[3] and a real camera.

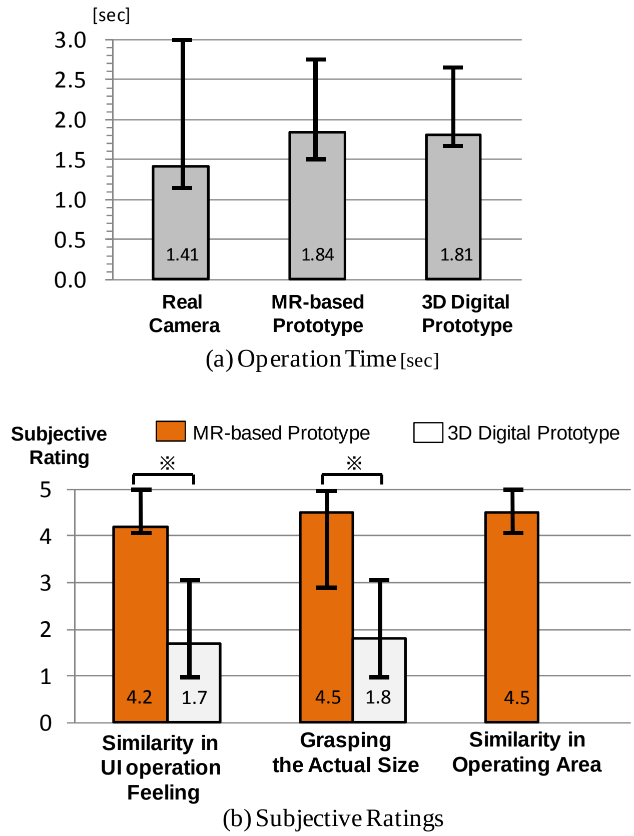

Fig. 5 Result of the user test

As shown in Fig.5(a), the results showed that the difference in operation time was small between the proposed prototype and the real product.

On the other hand, as for the ratings, the subjects graded the following questions on a scale of 5 (5: *very close* / *well graspable*, 4: *somewhat close* / *somewhat graspable*, 3: *yes and no*, 2: *not so close* / *not so graspable*, 1: *completely different* / *completely ungraspable*);

- how similar in the UI operation feeling the prototype was to the real product,
- how accurately he/she could grasp the actual size of the UI area, and
- how the operable area of the MR-based prototype was close to the real product in case of left handed operation.

As shown in Fig.5(b), there were significant differences in the subjective grading between the mixed-reality based prototype and the 3D digital prototype. The result of the third question also indicated higher reality levels of the proposed mixed reality based prototype over conventional digital prototypes.

V. Conclusion and Future Works

A mixed reality based digital prototyping environment for UI design of handheld information appliances with markerless tracking was proposed. Satisfactory performances of tracking speed, accuracy and occlusion robustness were realized. The user test results showed higher reality levels and better correlation with the real product of the proposed prototype over conventional digital prototypes.

The simplified mesh model for tracking and feature point sampling still has to be made manually from the 3D CAD model. Automating this process using SIFT or SURF will be our future work.

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