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Draft Standard for Augmented Reality on Mobile Devices-General Requirements for Software Framework, Components and Intergration

Developed by the

Virtual Reality and Augmented Reality Standards Committee

of the

IEEE Consumer Technology Society

Approved 23 Sep 2020

IEEE SA Standards Board

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[[1]](#footnote-1)•

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Introduction

This introduction is not part of P/D<draft\_number>, Draft<Gde./Rec. Prac./Std.> for .

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Contents

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Draft Standard for Augmented Reality on Mobile Devices-General Requirements for Software Framework, Components and Intergration

1. Overview
   1. Scope

This standard specifies the general technical framework, components, integration, and main business processes of augmented reality systems applied to mobile devices, and defines its technical requirements, including functional requirements, performance requirements, safety requirements and corresponding test methods.

This standard is applicable to the design, development, and management of augmented reality enabled applications or features of applications on mobile devices.

* 1. Purpose

This document will not include a purpose clause.

* 1. Word usage

***<This subclause is mandatory and shall appear after the Scope and Purpose (if included).>***

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals is *required to*).[[2]](#footnote-2),[[3]](#footnote-3)

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals is *recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals is *permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals is *able to*).

1. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ISO IEC 18039 Information technology — Computer graphics, image processing and environmental data representation — Mixed and augmented reality (MAR) reference model

ETSI GS Augmented Reality Framework (ARF) 003

1. Definitions, acronyms, and abbreviations
   1. Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause. [[4]](#footnote-4)

mobile device

component with camera, display screen and network functions, of which the location and motion information are detectable

Note: Mobile devices include wearable devices, phones, AR glasses or tablets with GPS, accelerometers, magnetometers and gyroscopes.

augmented reality

ability to mix in real-time spatially-registered digital content with the real world virtual object

computer-generated entity that is designated for augmentation in association with a physical object data representation

Note: In the context of MAR, it usually has perceptual (e.g. visual, aural) characteristics and, optionally, dynamic reactive behavior

target image

target object represented by a 2D image

target object

physical or virtual object that is designated, designed or chosen to allow detection, recognition and tracking, and finally augmentation AR anchor

coordinate system related to an element of the real world on which virtual content stays spatially-registered

Note: AR anchors help users to maintain the perception that static virtual content appears to stay at the same position and orientation in the real world localization

action for getting the spatial position and orientation of the specified object or device

relocalization

process of obtaining correct pose information and resetting the current pose of the mobile device by triggering the tracking recovery mechanism thereof according to the previously tracked historical position and orientation when the mobile device loses its location due to unexpected position mutation

6DoF tracking

action for calculating the position and orientation of mobile device relative to actual scene in real time

simultaneous localization and mapping

action for device (mobile terminal or robot, etc.) locating its pose in an unknown environment by observing the external environment, and then incrementally mapping the unknown environment through its position

illumination estimation

process of analyzing and calculating source illumination distribution information of physical scene from sensor or camera view

scale estimation

process of obtaining the real size information of the digital environment in relation to a coordinate system of the physical

absolute position error

average deviation between the true value and the estimated value of current position measured by the augmented reality system when the position of mobile device changes

absolute rotation error

average deviation between the true value and the estimated value of current rotation angle measured by the augmented reality system when the rotation angle of mobile device changes

relative position error

average deviation between the true variation and the estimated variation of the current position from the previous position measured by the augmented reality system when the position of mobile device changes

relative rotation error

average deviation between the true variation and the estimated variation of the current rotation angle from the previous rotation angle measured by the augmented reality system when the rotation angle of mobile device changes

3D map

3D digital representation for a scene, including the real size information, a set of images with known global positions and orientations, the visual connectivity among the images, as well as sparse 3D points of the scene and their observations in the images

* 1. Acronyms and abbreviations

2D: 2 dimensional

3D: 3 dimensional

6DoF: six　degrees　of　freedom

APE: absolute　position　error

AR: augmented　reality

ARE: absolute　rotation　error

CPU: central　processing　unit

FPS: frames　per　second

IMU: inertial　measurement　unit

RPE: relative　position　error

RRE: relative　rotation　error

SLAM: simultaneous　localization　and　mapping

1. System structure

The augmented reality system on mobile device consists of 13 modules such as real-time tracking and localization, scale estimation, target recognition and tracking, 3D reconstruction, virtual and real occlusion module, illumination estimation, face alignment, gesture recognition, interaction engine and rendering engine. The real-time tracking and localization module calculates 6DoF poses using the input data of mobile device; the scale estimation module calculates scale information using input data; the 3D reconstruction module reconstructs the 3D model of the scene using 6DoF pose, scale information and depth stream data; the virtual and real occlusion module realizes occlusion effect between virtual object and real environment using video stream and depth stream; the target recognition and tracking module realizes target recognition and tracking based on video stream; the illumination estimation module solves illumination information using video stream; the face alignment module detects face pose and structure using video stream; the gesture recognition captures gestures using video stream, the mobile device, if equipped with cloud computing service, also supports transmitting data to the cloud server via a network to realize cloud relocalization, cloud target recognition and cloud 3D reconstruction with higher efficiency, and transmitting the calculated 6DoF pose, target information and 3D model back to the processing unit of mobile device via the network; the information including face alignment and gesture recognition is summarized in the interaction engine to transfer action signals to digital signals, the information such as 6DoF pose, 3D model, virtual and real occlusion, target recognition and tracking, face alignment, gesture recognition and illumination are summarized in the rendering engine to achieve a realistic augmented reality effect, which is presented on the screen of video see-through AR device or optical see-through AR device.. See Figure 1 for the structural diagram of augmented reality system on mobile device. The requirements for sensor of mobile device related to augmented reality system shall meet the requirements of Annex A.

Cloud server

Cloud relocalization

Cloud 3D reconstruction

Cloud marker recognition

Display screen

Rendering engine

3D reconstruction

Virtual occlusion

Illumination estimation

Deep flow

Video flow

Marker recognition and tracking

Real-time tracking and localization

Scale estimation

Output

Mobile processing unit

Input



1. Structural diagram of augmented reality system on mobile device
2. Functional requirements
   1. Real-time tracking and localization

6DoF real-time tracking

The augmented reality system on mobile device shall estimate the pose of the device with respect to the real world coordinate reference system in 6DoF in real time.

Initialization

The augmented reality system on mobile device shall automatically initialize the scale information of the scene.

Local relocalization

When the mobile device loses its6DoF pose due to unexpected position mutation and so on, the augmented reality system on mobile device shall relocalize the device and reset its current pose locally.

Cloud relocalization

When the mobile device loses its 6DoF pose due to unexpected position mutation and so on, the augmented reality system on mobile device with device-cloud collaboration shall relocalize the device and reset its current pose at the cloud .

* 1. Scale

The augmented reality system on mobile device shall meet the following requirements:

a) obtain the scale information of the physical world;

b) register the virtual scene and the physical world in the same scale coordinate system;

c) achieve the 1:1 virtual-real fusion between virtual object and physical world.

* 1. Cloud localization based on a 3D map (增加3D map术语 友计)

The augmented reality system on mobile device shall meet the following requirements:

a) conduct a high-precision map for a defined scene, wherein, the high-precision map has a real scale, a set of images with known global pose, and the visual connectivity among the images, as well as sparse 3D points of the scene and observation in the images;

b) upload the image to the cloud services, and calculate the 6DoF pose in the high-precision map coordinate system;

c) extract image features at the mobile end, and upload them to the cloud for localization.

* 1. Target recognition and tracking

Recognition and tracking of target image

The augmented reality system on mobile device shall meet the following requirements:

a) recognize the target image in the defined scene;

b) perform 6DoF pose tracking for the target image in the defined scene;

c) trigger the augmented reality effect when the predefined specific target is recognized.

Recognition and tracking of target object

The augmented reality system on mobile device shall meet the following requirements:

a) preprocess the texture or structure information of the target object in a real scene;

b) compare the real-time information from the camera with the processed information to match the 2D information with 3D information;

c) understand the position and orientation of 3D object in a scene.

Cloud target recognition

The augmented reality system on mobile device with device-cloud collaboration shall meet the following requirements:

a) recognize the image frame with target image uploaded to the cloud by a user using computing resources of the cloud server, and return the position and orientation information of the target image of the frame to the user end;

b) recognize the image frame with 3D object uploaded to the cloud by a user using the computing resources of the cloud server, and return the position and orientation information of the 3D object of the frame to the user end.

* 1. 3D reconstruction

Plane detection and anchor localization

* + - * 1. Single plane reconstruction and anchor localization

The augmented reality system on a mobile device shall meet the following requirements:

a) support the detection of horizontal planes and vertical planes;

b) understand the main horizontal plane of the real scene, and localize or render the anchor on it;

c) recognize the 3D points on the plane, determine the position of plane and expand it;

d) detect the single plane in the real scene;

e) reconstruct the single plane and localize the anchor.

* + - * 1. Multiple-plane reconstruction and anchor localization

For a scene containing multiple planes, the augmented reality system on a mobile device should meet the following requirements:

a) understand the multiple planes (including horizontal planes and vertical planes) of the real scene, and localize or render the anchors on the planes;

b) recognize the 3D points on the plane, determine the position of plane and expand it;

c) detect the multiple planes in the scene;

d) reconstruct the multiple planes and localize the anchors.

* + - * 1. Automatic plane position adjustment

When the frame poses updated by loop closure or any other optimizations, the augmented reality system on a mobile device shall meet the following requirements:

a) automatically adjust the position of planes according to the optimized frame poses;

b) automatically adjust the position of anchors on the planes.

Dense point cloud reconstruction and anchor localization

When placing virtual objects on a non-planar complex scene, the augmented reality system on a mobile device shall meet the following requirements:

a) support incremental and real-time expands;

b) reconstruct the 3D dense point cloud of the scene, each point contains the information of position, normal and color;

c) calculate the position and normal of the anchor on the dense point cloud.

Dense mesh reconstruction and anchor localization

To perform complex effects of mixing virtual and actual reality in a real environment, such as occlusion, shadow and collision, the augmented reality system on a mobile device shall meet the following requirements:

a) reconstruct the dense 3D mesh of the scene;

b) calculate the position and normal of the anchor on the mesh.

Cloud 3D reconstruction

The device-cloud cooperated augmented reality system shall meet the following requirements:

a) support incremental and real-time expands;

b) perform 3D reconstruction on the cloud with the keyframes uploaded by the mobile device;

c) align the reconstruction result to the unified coordinate;

d) load or display the reconstruction information.

* 1. Illumination estimation

The augmented reality system on mobile device shall estimate the global illumination of the surrounding physical world environment used for the rendering of virtual object and virtual scene from the sensor or camera view.

* 1. Face alignment

The augmented reality system on mobile device shall meet the following requirements:

a) predict 106 facial key points including eyes, eyebrows, nose, mouth and face contour;

b) achieve at least 85% accuracy rate in complex conditions such as large head poses, different illumination conditions or extreme expressions.

* 1. Gesture recognition

The augmented reality system on mobile device shall meet the following requirements:

a) detect hand bounding boxes in the defined scene;

b) classify specific hand gestures based on image classification.

* 1. Rendering engine

The augmented reality system on mobile device shall meet the following requirements:

a) render dynamic/static virtual object in real time;

b) fusion of virtual of objects and the physical world with matching camera parameters;

c） correctly respond to the illumination changes in the real world.

* 1. Virtual and real occlusion

The augmented reality system on mobile device shall realize the occlusion between virtual object and real environment, including the occlusion between virtual object and static background environment and that between virtual object and dynamic foreground.

* 1. Asynchronous time warp

For optical see-through devices, before sending the rendered image to the display screen, the augmented reality system on mobile device shall be able to predict the pose at the future time when user sees virtual content, and warp the rendered image correspondently.

1. 6 Performance requirements
   1. Real-time tracking and localization

6DoF real-time tracking

Under the movement types and test scenes covered by the benchmark test dataset described in this document, the 6DoF real-time tracking of augmented reality system on mobile device shall meet the following requirements:

a) the frame rate is not less than 24fps;

b) the tracking accuracy rate is not less than 95%, that is, the number of frames that meet the following requirements in the test dataset is not less than 95% of the total number of frames:

1) APE is less than 10cm or less than 5% the maximum moving distance of the camera (whichever is greater);

2) ARE is less than 6°;

3) the relative position error within 0.1s does not exceed 3cm;

4) the angle error within 0.1s does not exceed 2°.

Initialization

The initialization of augmented reality system on mobile device shall meet the following requirements:

a) the initialization time shall be less than 3s;

b) the initialization quality error shall be less than 10, the defined initialization duration is tinit, the initialization scale estimation error is€scale, and the initialization quality €init=tinit\*(€scale+0.01)0.5.

Local relocalization

The local relocalization of augmented reality system on mobile device shall meet the following requirements:

a) the success rate of relocalization is not less than 90%, that is, the number of relocalizations that meet the requirements of the following items 1) and 2) in the test dataset is not less than 90% the number of relocalizations that meet the requirement of item 1):

1) the user puts the mobile device back to the position before the tracking loss to complete the relocalization;

2) the deviation between the relocalized position and the estimated position before the tracking loss is less than 5cm or less than 5% the median value of the depth of the picture taken by the camera (whichever is greater);

b) the relocalization time does not exceed 2s if succeed;

c) the tracking robustness error shall be less than 10, the defined tracking loss time percentage isαlost, the relocalization error is €RL and the position error is €APE, and the robustness error is €R=(αlost+0.05)(€RL+0.1\*€APE).

Cloud relocalization

The cloud relocalization of augmented reality system on mobile device shall meet the following requirements:

a) the success rate of relocalization is not less than 90%, that is, the error between the relocalized position in the test dataset and the true value is less than 10cm or less than 5% the median value of the depth of the picture taken by the camera (whichever is greater);

b) the relocalization time does not exceed 2s if succeed.

* 1. Scale estimation

The scale estimation of augmented reality system on mobile device shall meet the following requirements:

a) the deviation between the estimated value of actual environment and its true value does not exceed 15%;

b) the time does not exceed 2s.

* 1. Cloud localization based on a high-precision map

The cloud localization based on a high-precision map for augmented reality system on mobile device shall meet the following requirements:

a) the success rate of cloud localization based on a high-precision map is not less than 90%. A successful localization requires that the error between the localized position and the true value is less than 10cm or less than 5% the median value of the depth of scene captured by the camera (whichever is greater);

b) the localization time does not exceed 2s if succeed.

* 1. Target recognition and tracking

Recognition and tracking of target image

The recognition and tracking of target image for augmented reality system on mobile device shall meet the following requirements:

a) the recognition and tracking of not less than 4 plane targets shall be supported at the same time;

b) in the case of successful recognition, the recognition delay of single plane target does not exceed 0.5s;

c) the recognition accuracy is not less than 90%, that is, the average deviation between the projection contour of target image under the estimated pose in the test dataset and the true value is not greater than 5 pixels or 1% the larger value of the width and height of the true value contour (whichever is greater), and the number of frames for target image is not less than 90% the total number of frames;

d) the tracking frequency of single-plane target is not less than 24fps;

e) the tracking frequency of multiple-plane target is not less than 20fps.

Recognition and tracking of target object

The recognition and tracking of target object for augmented reality system on mobile device shall meet the following requirements:

a) the frequency is not less than 24fps;

b) in case of successful recognition, the recognition time does not exceed 1s;

c) the error between the tracked position and the true value is not greater than 3cm/m, or not greater than 3% the maximum moving distance of object (whichever is greater);

d) the recognition accuracy is not less than 90%, that is, the average deviation between the projection contour of target object under the estimated pose in the test dataset and the true value is not greater than 5 pixels or 1% the larger value of the width and height of the true value contour (whichever is greater), and the number of frames for target object is not less than 90% the total number of frames.

Cloud target recognition

In case of successful recognition, the cloud target recognition time (excluding network transmission delay) of augmented reality system on mobile device shall not exceed 0.2s.

* 1. 3D reconstruction

Plane detection

The plane detection of augmented reality system on mobile device shall meet the following requirements:

a) the process rate is consistent with 6DoF tracking;

b) the position error of plane does not exceed 2cm/m.

Dense point cloud reconstruction

The dense point cloud reconstruction of augmented reality system on a mobile device shall meet the following requirements:

a) the process rate for is consistent with 6DoF tracking;

b) the position error of dense point cloud does not exceed 3cm/m.

Dense mesh reconstruction

The dense mesh reconstruction of augmented reality system on a mobile device shall meet the following requirements:

a) the process rate is consistent with 6DoF tracking;

b) the geometric error of dense mesh does not exceed 3cm/m.

* 1. Illumination estimation

The illumination estimation of augmented reality system on mobile device shall meet the following requirements:

a) the response time to environmental changes does not exceed 1s;

b) the error between the estimated value and the true value of the scene illumination shall not exceed 0.3 (the illumination value is uniformly normalized to the range of 0~1).

* 1. Face alignment

The face alignment of augmented reality system on mobile device shall meet the following requirements:

a) the frequency is not less than 30 fps;

b) the prediction accuracy shall not less than 99%;

* 1. Gesture recognition

The gesture recognition of augmented reality system on mobile device shall meet the following requirements:

a) in case of successful recognition, the recognition time does not exceed 20ms;

b) the recognition accuracy shall not less than 95%.

* 1. Rendering engine

The rendering engine of augmented reality system on mobile device shall meet the following requirements:

a) the rendering frame rate is not lower than the frame rate of video captured by the camera;

b) the rendering resolution is not lower than the resolution of video captured by the camera.

* 1. Virtual and real occlusion

The virtual and real occlusion of augmented reality system on mobile device shall meet the following requirements:

a) the frame rate of image depth map acquisition and occlusion processing is the same as that of 6DoF tracking;

b) the deviation of the occlusion edge does not exceed 5 pixels or 1% the larger value of the width and height of the picture (whichever is greater);

c) the error rate of the occlusion relationship in the picture does not exceed 10%.

* 1. Asynchronous time warp

The asynchronous time warp of augmented reality system on optical see-through device shall meet the following requirements:

a) the frame screen refresh rate is constant and not less than 60Hz;

b) the translation error of predicted pose is less than 1cm, and the rotation error is less than 0.5°.

* 1. Running

CPU and memory occupancy

In the monocular scheme, the augmented reality system on mobile device shall meet the following requirements when running basic tracking and sparse point cloud mapping:

a) the CPU occupancy rate is not greater than 50%;

b) in a 5m×5m room, the memory occupancy does not exceed 500MB.

Algorithm running efficiency

The running frame rate of augmented reality system on mobile device shall not be less than 20fps.

1. Test method
   1. Test environment

In a 5m×5m laboratory, the standard test scene is arranged according to the following requirements:

a) arrange four light source modes on the ceiling of room, i.e. red, green, blue and white, and keep each light source diffused to ensure an uniform illumination in the scene; the wavelength of red light, green light and blue light is respectively 700nm, 550nm and 460nm, and the white light is the mixture of red, green and blue lights in the same proportion. The illumination of each light source is allowed to be adjusted within the range of 20~200lx;

b) in the scene, three walls and a square table are available, with patterned wallpaper on the wall surface and patterned tablecloths on the square table;

c) place sundries on the corners of three walls and on the desktop;

d) arrange five target images and five target objects in the scene;

e) refer to the public datasets such as ZJU - SenseTime VISLAM Benchmark and NEAR-VI-Dataset for benchmark dataset.

* 1. Function test method

Real-time tracking and localization

* + - * 1. 6DoF real-time tracking

The 6DoF real-time tracking function of mobile device is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) move in different ways by holding the mobile device and enable the augmented reality system;

c) observe the visual track of the device and the position of the virtual object on the display screen.

* + - * 1. Initialization

The initialization function of mobile device is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) move in different ways by holding the mobile device and enable the augmented reality system;

c) in the initial phase, observe the visual track of the device and the position of the virtual object on the device display screen.

* + - * 1. Local relocalization

The local relocalization function of mobile device is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) allow the algorithm to fully construct the scene map information by scanning the scene;

c) quickly shake the device or occlude the camera for a long time, so that the algorithm enters the tracking failure state;

d) re-scan the scene for relocalization. The successful localization (the virtual object is restored to its original position) means that the augmented reality system has the function of local relocalization; otherwise, it does not have the function of local relocalization.

* + - * 1. Cloud relocalization

The cloud relocalization function of mobile device is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) allow the algorithm to fully construct the scene map information and place it at the cloud by scanning the scene in advance;

c) quickly shake the device or block the camera for a long time, so that the algorithm enters the tracking failure state;

d) ensure the smooth network of mobile device, and re-scan the scene for relocalization. The successful localization (the virtual object is restored to its original position) means that the augmented reality system has the function of cloud relocalization; otherwise, it does not have the function of cloud relocalization.

Scale estimation

The scale estimation function of mobile device is tested by observing whether the size of virtual object is close to the real size after successful scale estimation, thus judging whether the augmented reality system has the function of scale estimation.

Cloud localization based on a high-precision map

The function of cloud localization based on a high-precision map for mobile device is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) scan the scene in advance to construct a high-precision map of the scene which meets those specified in 5.3.a, and deploy it at the cloud;

c) ensure the smooth network of mobile device, and send images or features to the cloud for localization. The successful localization (virtual object appears in the correct position of the scene) means that the augmented reality system has the function of cloud localization based on a high-precision map; otherwise, it does not.

Target recognition and tracking

* + - * 1. Recognition and tracking of target image

The recognition and tracking function of target image is tested according to the following method:

a) adjust the illumination color of the test environment to white light with the illumination of 100lx;

b) scan and shoot the target image with mobile device in the test environment, and judge whether the augmented reality system is able to successfully recognize and track target image by observing the presence of virtual AR content and its position on the device display screen.

* + - * 1. Recognition and tracking of target object

The recognition and tracking function of target object is tested by scanning and shooting target object with mobile device in the test environment, and observing the correct presence of virtual AR content and its position on the device display screen, thus judging whether the augmented reality system is able to successfully recognize and track target object.

* + - * 1. Cloud target recognition

The recognition function of cloud target is tested by ensuring the smooth network of mobile device, scanning and shooting the target in the test environment, uploading the scene video stream to the cloud platform through the mobile device, and observing the correct presence of virtual AR content and its position on the device display screen, thus judging whether the augmented reality system is able to successfully recognize target image and target object at the cloud.

3D reconstruction

* + - * 1. Plane detection

The plane detection function is tested according to the following method:

a) adjust the illumination color of the test environment to white light and set the illumination to 100lx;

b) perform plane detection in the test environment on a mobile device to confirm if this function is available, and check whether the augmented reality system can detect multiple planes and these planes should be incrementally expanded in real-time.

* + - * 1. Dense point cloud reconstruction

The function is tested by performing dense point cloud reconstruction on a mobile device in the test environment, and confirm if this function is available. The reconstructed dense point cloud should be incrementally expanded in real-time.

* + - * 1. Dense mesh reconstruction

The function is tested by performing dense mesh reconstruction on a mobile device in the test environment, and confirm if this function is available. The reconstructed dense mesh should be incrementally expanded in real-time.

Illumination estimation

The illumination estimation function is tested according to the following method:

a) switch red, green, blue and white light sources in the test environment, and adjust different illumination;

b) observe whether the color of virtual object is consistent with the illumination of test environment, and whether the color will change with the illumination change, thus judging whether the augmented reality system has the function of illumination estimation.

Face alignment

The face alignment function shall be tested according to the following methods:

a) record a face video in different scenes;

b) the successful prediction of 106 face landmarks means that the augmented reality system has the function of face alignment.

Gesture recognition

The gesture recognition function shall be tested according to the following methods:

a) record a hand video in different scenes;

b) if the mobile device can predict the hand gesture correctly in the video, the augmented reality system has the function of gesture recognition.

Rendering engine

The rendering engine function is tested by moving in different ways, and observing the rendering effect displayed on the screen of mobile device, thus judging whether the augmented reality system has the following functions:

a) render dynamic/static virtual objects in real time;

b) closely fit the virtual object and the physic world;

c) correctly respond to the illumination changes in the physic world.

Virtual and real occlusion

The virtual and real occlusion function is tested according to the following method:

a) look for a scene with complex depth of field hierarchy;

b) shoot the scene with a mobile device, and enable the augmented reality system, then place dynamic virtual objects in the picture of mobile phone scene to realize the occlusion effect between virtual objects and real scenes (including static background and dynamic foreground) through augmented reality system, thus judging whether the augmented reality system has the function of virtual and real occlusion.

Asynchronous time warp

The function of asynchronous time warp is tested by wearing the above-mentioned optical see-through device in a laboratory with arbitrary head motion, lauching the augmented reality system, loading the virtual scenes with different complexities, recording the 6DoF predicted trajectory and comparing it with the SLAM trajectory, and observing the rendering effect displayed on the mobile device screen, in order to judging whether the augmented reality system has the following functions:

a) whether the frame rate is stable and the rendered image is smooth without delay;

b) whether the rendered image jitter, or is not updated during the movement.

* 1. Performance detection method

Real-time tracking and localization

* + - * 1. 6DoF real-time tracking

The 6DoF real-time tracking performance is tested according to the following method:

a) construct a benchmark dataset for AR precision evaluation, wherein, the dataset shall cover data for different scenes and motions, including basic SLAM operation data such as image data, IMU sensor data and corresponding calibration parameters; true value data (which can be obtained by motion capture system) shall be provided; a standard public dataset can also be used as a benchmark dataset;

b) build a mobile data acquisition tool supporting off-line running algorithm, which can read the benchmark dataset and run the algorithm normally;

c) run the algorithm based on the benchmark data, and record the 6DoF poses of all image frames and single frame processing time;

d) evaluate indicators such as APE, ARE, RPE, and RRE of the algorithm with the aid of precision evaluation tools to measure the algorithm precision;

e) evaluate the accuracy and frame rate of the algorithm.

* + - * 1. Initialization

The initialization performance of mobile device is tested according to the following method:

a) construct a benchmark dataset for AR precision evaluation, wherein, the dataset shall cover data for different scenes and motions, including basic SLAM operation data such as image data, IMU sensor data and corresponding calibration parameters; true value data (which can be obtained by motion capture system) shall be provided; a standard public dataset can also be used as a benchmark dataset;

b) build a mobile data acquisition tool supporting off-line running algorithm, which can read the benchmark dataset and run the algorithm normally;

c) run the algorithm based on the benchmark data, and record the 6DoF poses of all image frames and single frame processing time;

d) evaluate indicators such as initialization time and initialization quality of the algorithm with the precision evaluation tools to measure the initialization performance.

* + - * 1. Local relocalization

The local relocalization performance is tested according to the following method:

a) acquire the following data with the mobile data acquisition tool in 8.3.1.1:

1) allow the algorithm to fully construct the scene map information by scanning the scene;

2) quickly shake the device or occlude the camera for a long time, so that the algorithm enters the tracking failure state;

3) re-scan the scene for relocalization.

b) evaluate the local relocalization success rate, relocalization time and relocalization precision based on above data.

* + - * 1. Cloud relocalization

The cloud relocalization performance is tested according to the following method:

a) acquire the following data with the mobile data acquisition tool in 8.3.1.1:

1) allow the algorithm to fully construct the scene map information by scanning the scene;

2) quickly shake the device or occlude the camera for a long time, so that the algorithm enters the tracking failure state;

3) re-scan the scene and transmit it to the cloud for relocalization.

b) evaluate the cloud relocalization success rate, relocalization time and relocalization precision based on above data.

Scale estimation

The scale estimation performance is tested as follows: generate the required 6DoF parameters and true value data of algorithm by reference to the data acquisition method in 8.3.1.1, and evaluate the 6DoF pose scale error of the algorithm by comparing the algorithm pose parameters with the true value data.

Cloud localization based on a high-precision map

The performance of cloud localization based on a high-precision map is tested according to the following method:

a) construct a benchmark dataset covering different scenes for evaluating the cloud localization performance based on a high-precision map, construct a high-precision map meeting those specified in 5.3.a for each scene, and acquire test images with a mobile device. The ground truth positions of which can be obtained by a motion capture system or measuring devices like total station;

b) locate all test measuring devices like;

c) count the localization success rate, localization precision and localization time.

Target recognition and tracking

* + - * 1. Recognition and tracking of target image

The recognition and tracking performance of target image is tested according to the following method:

a) record the execution time of identification and tracking algorithm for each frame in a log, and count the average recognition and tracking time of target image per frame within the execution time of not less than 5min, including:

1) respectively test the recognition time of single target image and the average recognition time of five target images;

2) respectively test the tracking time of single target image and the average tracking time of five target images.

b) test the recognition success rate of target image, including the success rate under different angles, different distances and different illumination intensities.

* + - * 1. Recognition and tracking of target object

The recognition and tracking performance of target object is tested according to the following method:

a) record the execution time of identification and tracking algorithm for each frame in a log, and count the average recognition and tracking time of target object per frame within the execution time of not less than 5min, including:

1) respectively test the recognition time of single target object and the average recognition time of five target objects;

2) respectively test the tracking time of single target object and the average tracking time of five target objects.

b) test the recognition success rate of target object, including the success rate under different angles, different distances and different illumination intensities.

* + - * 1. Cloud target recognition

The recognition performance is tested as follows: upload the scene video stream to the cloud platform through the mobile device under the condition of smooth network of tested mobile device, and then test the recognition speed and success rate of target images and target objects by cloud, including:

a) test the average network time, algorithm time and success rate of target image recognition;

b) test the average network time, algorithm time and success rate of target object recognition.

3D reconstruction

* + - * 1. Plane detection

The performance of plane detection is tested according to the following method:

a) construct multiple plane models as ground truth with modeling software (such as 3dsmax or Maya) according to the measured size of the scene;

b) evaluate the position error between each detected plane and the ground truth;

c) record the single frame execution time of plane detection algorithm in the log, and count the average detection time of each frame with the total execution time not less than 5min, including single plane detection and five planes detection.

* + - * 1. Dense point cloud reconstruction

The performance of dense point cloud reconstruction is tested according to the following method:

a) take an accurate 3D model of a scene scanned by a 3D scanner as ground truth;

b) perform dense point cloud reconstruction on a mobile device for the scene, and evaluate the position error between the reconstructed dense point cloud and the ground truth;

c) record the single frame execution time of dense point cloud reconstruction algorithm in the log, and count the average reconstruction time of each frame with the execution time not less than 5min.

* + - * 1. Dense mesh reconstruction

The performance of dense mesh reconstruction is tested according to the following method:

a) take an accurate 3D model of a scene scanned by a 3D scanner as ground truth;

b) perform dense mesh reconstruction on a mobile device for the scene, and evaluate the geometric error between the reconstructed dense mesh and the ground truth;

c) record the single frame execution time of dense mesh reconstruction algorithm in the log, and count the average reconstruction time of each frame with the total execution time not less than 5min.

Illumination estimation

The illumination estimation performance is tested according to the following method, and the estimated value is normalized to 0~1 by algorithm and the true value is normalized to 0~1 by system camera:

a) turn on the white light only, and measure the error between the estimated value and the true value of illumination color under 4 conditions where the illumination of the white light is 20lx, 100lx , 200lx and 300lx respectively;

b) turn on the red light only, and measure the error between the estimated value and the true value of illumination color under 4 conditions where the illumination of the red light is 20lx, 100lx, 200lx and 300lx respectively;

c) turn on the green light only, and measure the error between the estimated value and the true value of illumination color under 4 conditions where the illumination of the green light is 20lx, 100lx, 200lx and 300lx respectively;

d) turn on the blue light only, and measure the error between the estimated value and the true value of illumination color under 4 conditions where the illumination of the blue light is 20lx, 100lx, 200lx and 300lx respectively.

Face Alignment

The face alignment performance is tested as follows:

a) construct a benchmark dataset covering different scenes;

b) compute the accuracy of key points on above data.

Gesture recognition

The gesture recognition performance is tested as follows:

a) construct a benchmark dataset covering different scenes;

b) count the recognition success rate on above data.

Rendering engine

The rendering engine performance is tested as follows: provide static model and skeleton animation model in standard format, and use the estimated illumination to render, test the loading of static model and dynamic model, animation update and rendering results, and test the rendering resolution and running frame rate of rendering engine by tools of mobile device, such as Arm or Qualcomm frame GPU profiler tool.

Virtual and real occlusion

The virtual and real occlusion performance is tested according to the following method:

a) shoot the scene with a mobile device, and enable augmented reality system, then place dynamic virtual objects in the picture of mobile phone scene to realize the occlusion effect between virtual objects and real scenes (including static background and dynamic foreground) through augmented reality system, meanwhile, output the occlusion time of each frame to the log, and judge whether the frame rate can reach the frame rate of 6DoF tracking;

b) record five groups of real-time virtual and real occlusion frames with common frame cutting tools of mobile device, and give the frame information to five participants, each participant evaluates the edge accuracy and error rate of virtual and real occlusion in five groups of scenes, and calculate the average of these evaluation results to get the edge accuracy and correct rate of virtual and real occlusion of augmented reality system on mobile platform.

Asynchronous time warp

The asynchronous time warp performance is tested as follows:

a) provide scenes with static model in standard format and skeleton animation model with different complexity, and use the estimated illumination value and color value as ambient light illumination and color to render, test whether the rendering frame rate can be stabilized at a fixed frame rate of >60Hz, and test the running frame rate of rendering by common frame cutting tools of mobile device, such as Arm or Qualcomm frame cutting tool;

b) record the 6DoF predicted trajectory and the SLAM trajectory, then compare the two numerically.

Running

* + - * 1. CPU and memory occupancy test

After the augmented reality on mobile device platform is enabled, the built-in commands or system tools of operating system can be used to check the CPU and memory occupancy of the system process. The command or tool depends on the operating system on mobile device platform. For example, after the augmented reality system on the Android mobile device platform is enabled, the CPU occupancy rate of augmented reality system on mobile device can be checked by running the command line "adb shell top". The real-time memory occupancy of the process corresponding to the package name can be get by running the command line "adb shell dumpsys meminfo package name", and the CPU and memory occupancy of augmented reality system on mobile device process can be get by Profile tool of Android Studio; after the augmented reality system on the iOS mobile device platform is enabled, the CPU and memory occupancy of mobile device based augmented reality can be analyzed by using the Instruments tool of XCode.

* + - * 1. Algorithm running efficiency test

After the augmented reality system on mobile device platform is enabled, the algorithm running time of each frame of data is recorded in the log, and the maximum, minimum and average time for algorithm per frame can be counted based on the record within the algorithm execution time of not less than 5min.

(Informative)

**Sensor of mobile device related to augmented reality system**

## Exposure parameters

The camera shall have exposure parameter setting function.

The exposure time shall not exceed 20ms.

## Inertial measurement unit

IMU shall be able to measure the triaxial pose angle (or angular velocity) and acceleration of an object.

The IMU information frequency shall not be lower than 200Hz; clock shall be aligned with camera, and the time deviation shall not exceed 5ms.

## Focus mode

**Fixed focus mode**

The focus of a camera on the mobile device shall be at infinity by default where the automatic focusing is not enabled.

In single-shot focus mode, the focus will be determined by manual selection or at infinity by default and will not be changed upon enabling.

**Zoom mode**

In zoom mode, the camera shall be able to focus continuously for many times to improve the definition.

**Mode selection**

The camera in fixed focus mode shall be selected for augmented reality. If continuous focusing is adopted, the focus change shall be smooth.

The augmented reality system shall be equipped with a camera loopmotor.

## Time alignment

The mobile device shall be in alignment with the time on camera and sensors such as IMU, and the time stamp difference shall not exceed 5ms.

## Quality of camera image

The resolution of each frame of video captured by mobile device camera shall not be less than 720p.

## Depth camera

The mobile device depth camera shall be used to obtain spatial depth information in pictures, and is usually classified into the following two types with different implementation modes:

a) structured light camera

b) TOF camera

The frame rate of ordinary camera shall be an integral multiple of that of depth camera which shall not be less than 5fps.

The clocks of depth camera and ordinary camera shall be accurately calibrated and aligned, with a time deviation of not greater than 15ms.

The depth camera and ordinary camera shall be provided with accurate external parameter (relative pose) calibration. Under the image resolution of 640\*480, the deviation of pixel position respectively corresponding to the color and depth shall not exceed 2 pixels, and under the image resolution of 320\*240, the deviation shall not exceed 1 pixel.

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2. The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations. [↑](#footnote-ref-2)
3. The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact. [↑](#footnote-ref-3)
4. IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page. [↑](#footnote-ref-4)