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IoT-supported Cloud-based Mobile Augmented Reality

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Abstract— *While modern mobile augmented reality (AR) is already incredibly impressive, it also has many limitations. Because environmental awareness is an area where AR currently makes a lot of mistakes and there is obvious room for improvement, researchers have been working on architectures that may be able to help. In this paper we discuss efforts to enable next-generation mobile augmented reality via the internet of things (IoT). Augmented reality on next-generation mobile devices, in particular ensures the dependability and safety of the upcoming augmented reality applications. In one of these architectures, environmental sensors and actuators are used to provide additional information to mobile AR systems or to modify the state of the systems***.**

Keywords— *Mobile: augmented reality (AR): architectures: internet of things (IoT): applications*.

I. Introduction

In this paper we discuss efforts to enable next-generation mobile augmented reality via the internet of things. Augmented reality on next-generation mobile devices, in particular ensures the dependability and safety of the upcoming augmented reality applications. Researchers are creating systems that are context-aware and adapt to the environment and the user's status with the goal of making them so trustworthy that you might entrust your life to them, making them appropriate for health and safety-critical applications. There are numerous applications geared towards working on addressing the various aspects of this overarching goal, for example, researchers [26], [4], [23] seek to improve depth data processing and user collaboration in multi-user augmented reality systems, improving eye tracking's dependability and addressing some of its privacy issues. Others are actively working on several applications that contribute to greater confidence for customers; developing AR for surgery and AR that gives safety and security.

We'll discuss the architecture of the paradigm where mobile AR is supported by the environment around it, for example, security assurances on AR applications which guarantees that holograms would not be moving out of the way of critical things.

We'll discuss some of the limitations of mobile AR, particularly in terms of its environmental awareness, how age computing addresses some of those limitations, and how AR IoT and Edge can collaborate to advance AR. Mobile AR today is already incredibly impressive because it is truly able to blend the physical and the digital, and it enables experiences that are not possible with a traditional computer.

AR-assisted surgery (see Figure 1) and AR in an art gallery (see Figure 2) are two examples of projects, which are truly fusing the physical and the digital. In the surgical scenario, we take a pre-operative scan of the patient and overlay that scan directly with the patient's insurgent view. This enables the surgeon to directly target the part of the anatomy that he or she would like without having to turn the head away and mentally reproject the scan so it's the type of experience that truly relies on being able to merge the physical and the digital.

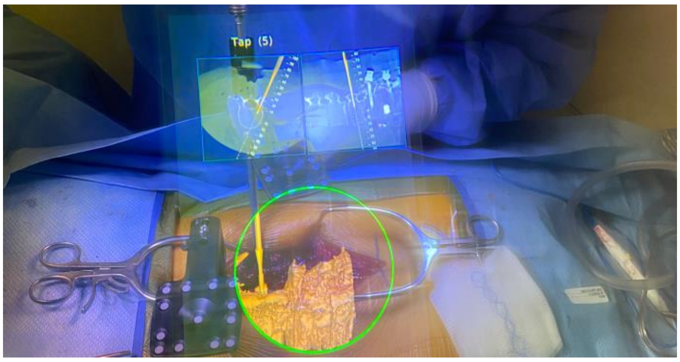


Fig. 1. Surgeon's operating view using augmented reality to superimpose medical scans and data in field of vision above patient's open surgical site. [7]

Fig. 2. Augmented Reality for Art. [8]

This paper consists of six sections. In Section II we give some of the current challenges facing IoT and mobile AR. In Section III we look at advances in these fields based on the literature. Section IV give examples of IoT-supported Mobile AR. Some contemporary breakthroughs and future work are outlined in Section V, while the conclusion in given in Section VI.

II. CHALLENGES

Eye tracking allows us to determine when a visitor is paying attention to a painting in a gallery. We can then create holographic enhancements [25] to the painting to overlay holograms with the user's perspective of the surrounding real world, which is something that isn't achievable with any other technology.

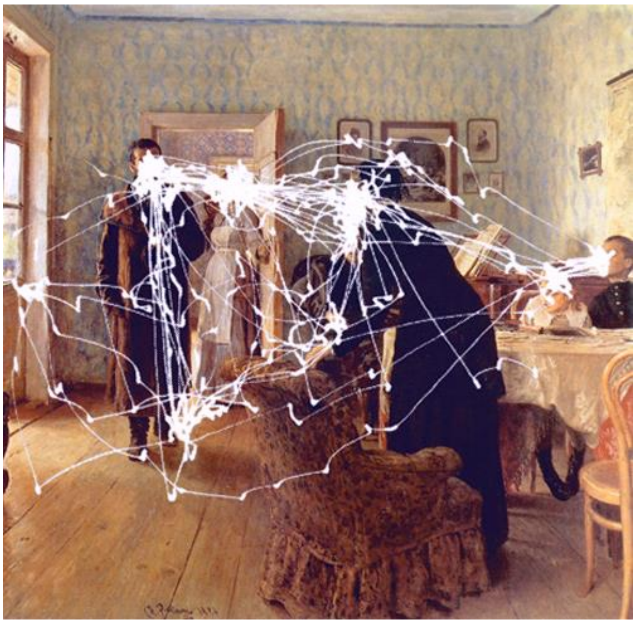


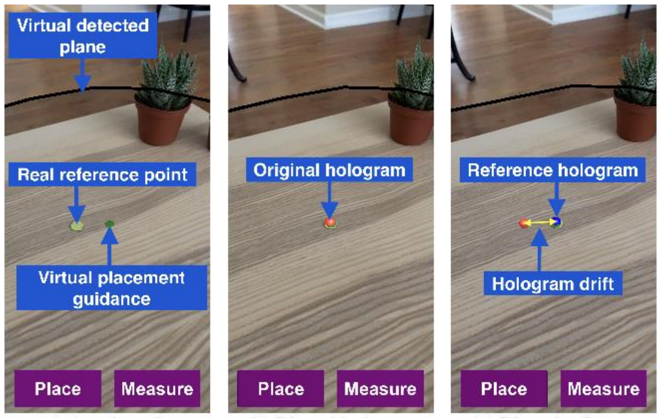
Fig. 3. Tracking the Gaze. Ilya Repin, “Unexpected Visitors” (or “They Did Not Expect Him”), 1884-1888. Oil on canvas. 63.19 x 65.95 in. The Tretyakov Gallery, Moscow, Russia. [10]

As a result, there is a lot of room for improvement in current AR. It takes a lot of resources to be able to understand the world around an AR device, and this is where AR devices frequently go wrong. As an example of where this mobile AR currently has a lot of limitations, and in order to merge physical and digital, you need to have a very good understanding of the physical, you can think of those mistakes as being as belonging to two categories semantic mistakes and spatial mistakes.

Incorrect interactions with the environment prevent you from engaging with the surface in the way you would like, or they simply result in the generation of incorrect holograms. Semantic [14] errors are errors in understanding the nature of the world around the device, so you do not see a sofa as a sofa or you see a cat as a dog.

The other sort of errors are spatial areas. Anyone who has used markerless AR has undoubtedly encountered spatial errors, see Figure 4. Scaling and positioning problems are common. Scaling areas are those where, as a result of depth mapping, a created hologram is either too big or too little for the surroundings, thus you see a chair that's enormous and an echo show that's too small.

This is solely as a result of the art device's inaccurate perception of depth, which makes the surface appear to be either closer or farther away than it actually is.



(a) App interface (b) Placed hologram (c) Placed reference

Fig. 4. Here To Stay: Measuring Hologram Stability in Markerless Smartphone Augmented Reality, [24]

An example is drift, or unintentional holographic motion [6], [5], [28]. In AR, this is a common scenario in which we place a hologram in one location, and as the user moves around and possibly returns to the location, the hologram moves. It may move slightly or it may move dramatically.

While expected drift for modern platforms is currently on the order of tens of centimetres, many instances of drift are so dramatic that they are unusable from the point of view of the experience, such as the example that is shown on the very right panel. As a result, while mobile AR is already truly remarkably impressive, major improvements are needed to make it reliably accurate.

III. ADVANCES

You may have heard about age computing; it's a paradigm that is used in a variety of contemporary applications. For example, for AR specifically, it can be used for remote rendering for coordinating multiple devices and for running additional intelligence on behalf of mobile devices; it's very challenging to run some of the most cutting-edge neural networks. It also plays a role in VR, coordinating drones (see Figure 5 for example), and in video analytics.

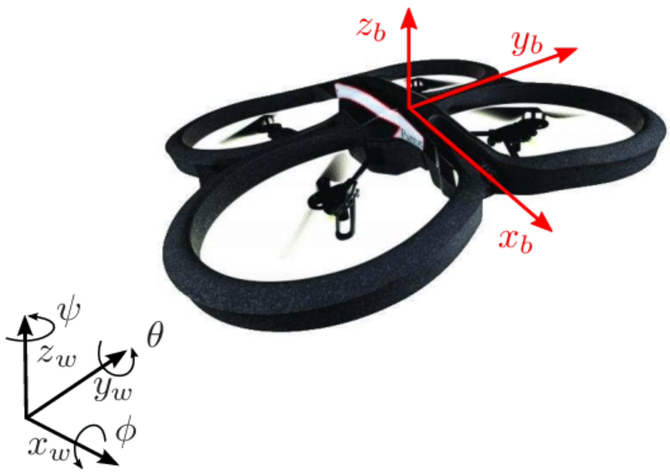


Fig. 5. The AR.Drone2 and its coordinate systems. The arrows of the rotation angles correspond to positive values. a simple (quadratic) transformation of

propellers' speeds that lead to an input vector that consists of four basic movements (throttle, roll, pitch, yaw). Parameters of such model are quadrotor's mass, gravitational acceleration, inertias, friction constants etc. The identification of these parameters is provided by a series of identification experiments, [19]

For example, researchers have been using edge to perform advanced neural network-based processing on behalf of mobile devices, such as improving depth data for paintings, as shown on the right of the screen, and cognitive context detection.

Researchers are also able to track user eye movements [27] to determine how engaged they are with the environment, such as when reading, programming, or conversing with someone. They then use this data on the edge server to feed into a deep neural network, and send this data back to the mobile device to adjust the state of the holographic experience.

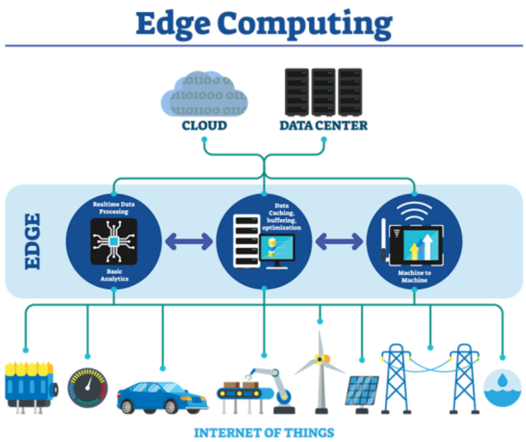


Fig. 6. Real-Life Use Cases for Edge Computing.

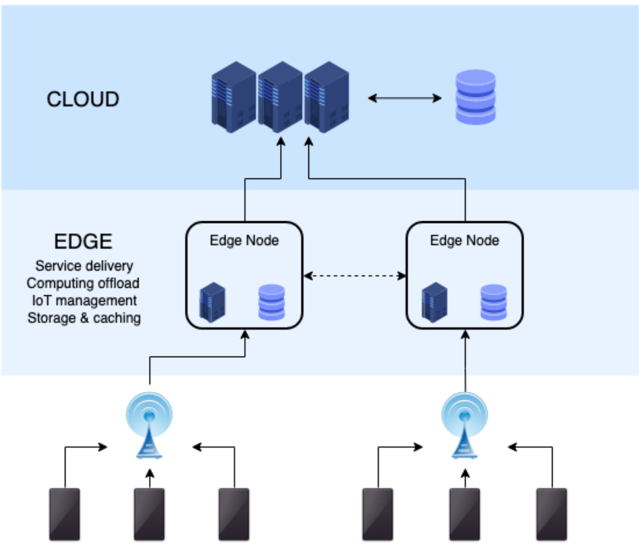


Fig. 7. The edge computing infrastructure. [18]

In a completely unrelated field, edge computing is actually used as a de facto standard for interacting with internet of things (IoT) devices, see Figure 6. As a result, the vast majority of IoT deployments today have a gateway or server that is used to coordinate and manage the IoT devices and, in some cases, run some intelligence on their behalf. This is a classic example of using edge computing to perform processing that's very difficult to do on a mobile device itself, see Figure 7 for edge computing processing architecture.

Now that mobile devices and the edge have merged with the internet of things, it begs the question of whether research can make this system work end-to-end and whether mobile devices can be used to browse the internet using AR [15]. The answer to both of these questions is yes, and some examples of how the internet of things can help AR include additional environmental sensing.

This paradigm is potentially very powerful since we are shifting the burden of environmental understanding and control from the user to environmental actuators like smart lights, shades, or displays. For example, you might think about turning on the light if you perceive the environment to be too dark for the mobile AR experience or you might think about lowering the shade if the environment has too much glare.

The user can theoretically adjust the state of the environment themselves, but that relies on the user being able to fully map the state of the environment to what's best for the mobile AR experience, which is a very tall order and would require a lot of time. We should be able to have an AR device do all of environmental understanding by itself, but it's very resource-intensive and takes a lot of user time.

It was a potentially very strong paradigm that converges IoT and AR. Overall, it is quite simple to hack together with many platforms and construct the basic interface between mobile AR and IoT.

IV. EXAMPLES

Some examples are an illustration of an IoT-based display that shows a marker [3]. The marker that it displays is programmable, so you can change its state depending on the environment or program it using the edge server. This is a complete end-to-end correspondence of mobile AR and an IoT-based display because the device that is currently being shown to be reading this marker would display different holograms depending on the state of the marker.

Another example is now given. You might imagine that the light would turn on if their core determines that the environment is too dark, for example, if the smart light bulb is connected to the edge server and changes its levels based on the metrics that are gathered by an ar app running over a google air core [13].

Yet another example is a room is constantly being surveyed by this camera server, which takes pictures of the lab and sends them to the edge server for processing [2]. On the edge server, we process the images by running various analytics, and we then use the inputs from the edge server to modify the algorithms and applications for the mobile AR.

The challenges come from making this more automatic. For example, it can be difficult to localise IoT devices precisely. You can hard code this but being able to do it more automatically would be highly desirable for many of these applications. You would also want to map the states of environmental actuators to the states of the environment, so you would want to say that if I lower the light or temperature,

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then the environment is in state A.

V. Breakthroughs and Future Work

Researchers been experimenting a lot with the idea of having environmental cameras that are surveying the scene and could assist AR devices in obtaining semantic awareness. For example, the extent of any actuator's action would vary in different times of day and different weather conditions. This is where some of the research challenges are.

In particular, one application of it might be to help provide a different perspective of the scene that a mobile AR device is seeing, see Figure 8. Overall, image recognition enables seamless and contextual mobile AR. For example, if I look at a surface and immediately recognise it as a table or sofa, that enables me to interact with it appropriately.

Fig. 8. Augmented Reality Furnishing App. [1]

Deep neural networks (DNNs) [9] are typically used to accomplish this, but the problem with them is that they frequently make mistakes. For example, they can be confused by objects in unusual poses, partially obscured objects, partially acutely obscured views captured by mobile cameras, and distortions. As a result, it's problematic if your mobile AR device captures images that are just a little bit blurry.

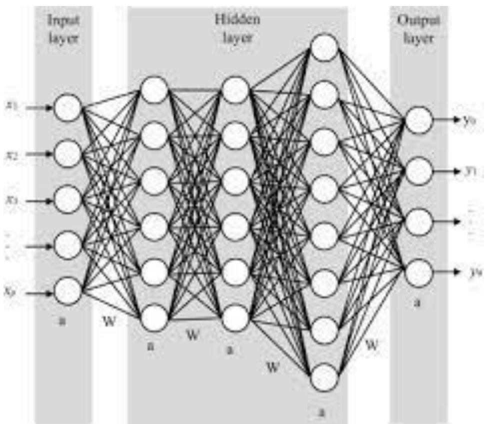

Fig. 9. Deep Neural Network (DNN). [20]

An image should help illustrate why taking multiple views of the same scene—in this case, a cat and a spool of thread—could provide us with additional information to enhance the quality of image recognition. Here, we took the exact same scene from two different perspectives and can put it through the same DNN algorithm.

If we can intelligently combine this information, we should be able to perform better in recognition than one of those perspectives alone because in one view we only see a cat and in the other we can see both things.

What some researchers have done in their research is create an architecture where photographs from various perspectives of the environment are sent to the edge server for processing [29]. Image recognition software is then performed on the edge, and the results are combined to enhance the total recognition. They specifically do this using a machine learning approach known as auxiliary assisted multi-view learning, which entails considering both the results and the enhanced confidence when making recognition decisions. They have shown that this significantly increases overall recognition accuracy, especially when mobile device captures are distorted by, for example, motion blur.

This is just one example of how a stationary camera can be used to aid in semantic awareness, but there are undoubtedly more. For instance, you might utilise your mobile AR device to provide knowledge of one area of the environment while employing stationary cameras to provide awareness of other areas.

You might also consider using stationary cameras to inform mobile AR devices of previous states of a space. For example, if you are in a room that is currently empty but was very busy five minutes ago, your application might be able to use this information and become aware of it thanks to these kinds of architectures.

The problem is that in order to be able to enable this kind of automatic adjustment of environmental conditions for spatial awareness right away, you need to be able to say that this particular set of conditions is associated with poor spatial awareness. As users, we learn spatial awareness as we interact with technology; for example, if you play with markerless AR, you'll get a feel for featureless spaces.

Researchers are developing a system that will allow them to automatically alter the state of the environment to increase stability. To do this, they are taking different environmental measures and developing classifiers to map those metrics to poor spatial stability.

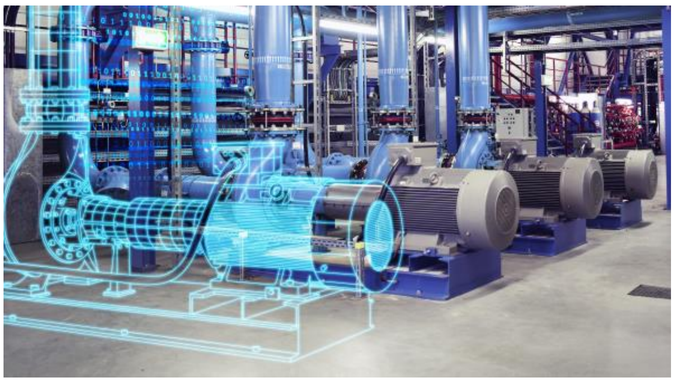

Fig. 10. Digital Twin. [16]

Some researchers [21], [17] are working on creating the proper kinds of digital twins (see Figure 10) in this place, so the issue is, what constitutes a typical space where you deploy AR experience? Is so-called semi-static space, neither static nor dynamic? Some parts change and some don't, so not all twins apply. How to get the right level of digital twin that's appropriate is very relevant. Overall, coming up with the best digital twin for these kinds of settings is a great research direction and it's something that will definitely be pursued in the future. For example, for the best rendering of for the best holographic rendering, you want to know where the light sources are and so you have to build twins that that incorporate that.

In the future, context awareness (see Figure 11 for example built for user-driven tour guides) in general for applications will absolutely increase based on a much more heavily censored phone itself. All the sensors double, triple the number and different types of applications beyond what's currently in a top of the contemporary phones. As sensors become higher in resolution with smaller footprints and lower power drain it seems like this is an extremely rich path going forward.

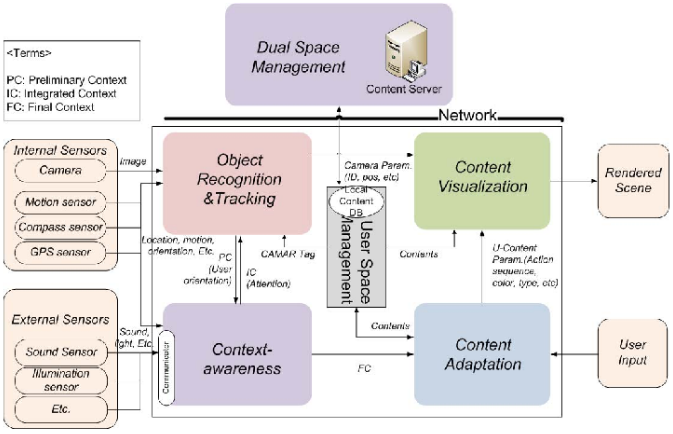

Fig. 11. Unified Context-Aware Augmented Reality Application Framework. [22]

Having heterogeneous hardware, sensors, and processing capabilities is one of the challenges. Some researchers use an age-centric approach in which they feed the data to the edge server for uniform processing. This doesn't solve the problem of heterogeneous hardware, but it does provide a single location for the execution over the long term. This can be a successful venture in the future.

VI. CONCLUSION

In conclusion, while modern mobile AR is already incredibly impressive, it also has many limitations. Because environmental awareness is an area where AR currently makes a lot of mistakes and there is obvious room for improvement, researchers have been working on architectures that may be able to help. In one of these architectures, environmental sensors and actuators are used to provide additional information to mobile AR systems or to modify the state of the systems. Future work including digital twins, increasing context awareness and using bio-inspired algorithms [12], [11] for image processing are promising directions.

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