Demo: Real-time X-Ray Vision via Augmented Reality with RF Sensing

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ABSTRACT

This demo presents X-AR, an Augmented Reality headset that enables its user to find and retrieve hidden items. X-AR leverages battery-less 3-cent Radio Frequency IDentification (RFID) tags that are already deployed on billions of items. As a user wearing X-AR moves in an environment, the headset transmits RF signals and leverages natural human mobility to locate RFID-tagged items. X-AR then guides the user toward the desired item for retrieval. We built a real-time prototype of this system on a Microsoft Hololens 2 AR headset with a conformal antenna, software radios, and an edge server. Our demo will enable any user to wear our X-AR prototype and use it to find and retrieve hidden items in a warehouse-like setting. Demo Video: youtu.be/bdUN21ft7G0

CCS CONCEPTS

• **Computer systems organization** → **Sensor networks**; • **Hardware** → *Wireless integrated network sensors*; • **Human-centered computing** → Mixed / augmented reality.

KEYWORDS

Wireless sensing, RF-Visual Sensing, Augmented Reality, Virtual Reality, RFID localization

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1 INTRODUCTION

There has been an increasing interest in the development of Augmented and Mixed Reality (AR/MR) technologies; specifically, in AR and MR headsets that immerse users with interactive holograms overlaid in physical space. The recent announcement of the Vision Pro by Apple as a public consumer device [3] indicates the huge investment companies are making in this technology and its potential to become a widespread device in future. In addition to general consumer applications, AR headsets have been developed to boost efficiency and accuracy in logistics, warehousing, and manufacturing.

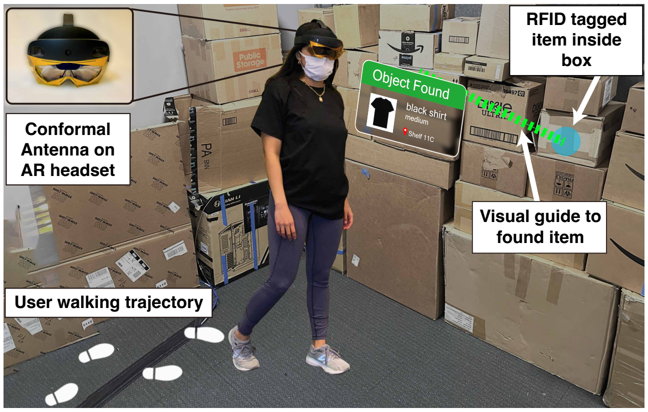

Figure 1: X-AR enable its user to see and locate hidden items in the environment by fusing AR and RF sensing.

However, current AR and MR headsets primarily sense the environment through their cameras, which makes them inherently limited to sensing what is visible to human eyes. Practical environments are very cluttered, for example, in warehouses and manufacturing plants, objects are packed inside boxes or under piles of other objects. In the case of a warehouse worker looking for an item that is hidden (e.g. inside a box), a standard headset would not be able to locate the item or help the user retrieve it.

In this demo, we present a real-time prototype of X-AR [5, 6], an AR headset that extends its user's perception beyond the line of sight by seamlessly fusing RF sensing with AR technology. X-AR truly augments human perception by allowing users to locate RFID-tagged objects, even when the target item is fully hidden under a pile of other objects or inside boxes. To do so, it leverages the UHF RFID tags that are already deployed on billions of items. These RF stickers are battery-less, cheap (3 cents), and widely adopted (93% of US retailers have already deployed them [2]).

X-AR is able to locate tags with high accuracy and guide users towards hidden RFID tagged objects through three main components: 1) a custom designed conformable, ultra light weight (<1g) and wide-band antenna that is mounted on the visor of AR headset, 2) AR-based wide-band Synthetic Aperture Radar (SAR) to locate RFID tagged items, 3) RF-based Dynamic User Interface to help the users find and retrieve target items with higher accuracy and efficiency. We tested X-AR on more than 20 users[1] and evaluated its performance. X-AR is able to locate fully occluded RFID tagged items with a median accuracy of 9.5 cm.

Contribution: This demo builds on our recent work [5, 6] to deliver the first *real-time* prototype that allows users to find and retrieve hidden items. A user will wear our headset, select the item they want to retrieve, and start moving in a warehouse-like setup. The device will leverage natural human mobility to locate the target

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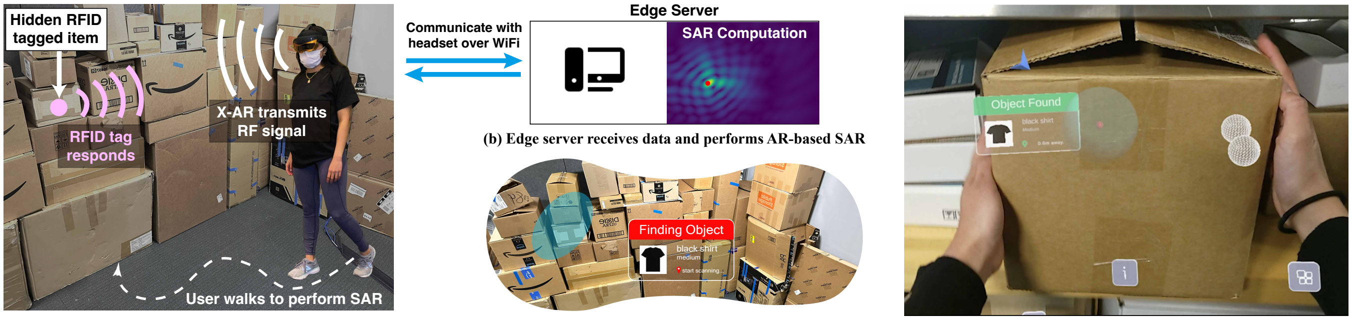
[1] This study was approved by the institution's IRB



(a) Wideband conformal antenna sensing the environment

(b) Edge server receives data and performs AR-based SAR

(c) Dynamic RF-based user interface during localization process

(d) User interface once object is localized

Figure 2: System Overview. a) X-AR uses its custom antenna mounted on the headset to send RF signals and collects the RFID tag responses as the user moves. b) The headset sends location and RF information to the edge server that performs AR-based SAR. c) The headset receives instructions from the edge server and displays the UI to assist with localization. d) When the target item is confidently located, X-AR displays UI to guide the user to the target item.

item and guide the user towards it for retrieval, even if it is inside a closed box.

2 SYSTEM OVERVIEW

X-AR sends RF signals to power up the RFID tags in the environment. As the user wearing the headset moves, X-AR uses its custom-designed antenna to receive the RFID tags' responses to locate them. During this time, X-AR guides the user through a dynamic user interface to improve the accuracy and efficiency of localization.

2.1 Wide-band Conformal Antenna

In order to send and receive RF signals to locate RFIDs like in Fig. 2(a), X-AR requires an antenna that meets specific criteria. Past work [4, 7, 9] has shown that 200 MHz of bandwidth is needed to accurately locate RFID tags. Additionally, the antenna must be lightweight for user comfort since it will be placed on the headset. Finally, its form factor must seamlessly integrate with the headset without blocking any of the cameras or sensors. Thus, we designed a custom, lightweight, wide-band conformal antenna, as shown in Fig. 1, with 200 MHz of bandwidth on a kapton substrate to meet these requirements. Its center frequency is 915MHz to match standard UHF tags. X-AR sends wideband RF signals through this antenna and collects the RF responses from the tags in the environment using RFID's EPC Gen2 protocol [1].

2.2 AR-based Synthetic Aperture Radar

When the target RFID tag responds, X-AR uses the collected wide-band RF measurement to estimate the channel between the antenna and target RFID tag. As the user walks in the environment, X-AR collects additional wide-band measurements and estimates the channels at these new locations. Recall that the custom designed antenna does not cover any of the AR headset's cameras. As a result, X-AR leverages the built-in visual inertial odometry of the AR headset to locate and self-track in the environment. X-AR then interpolates these locations over time and performs an additional transformation to determine the location of the antenna in the environment. Using the estimated channels and corresponding antenna locations, X-AR performs AR-based Synthetic Aperture Radar (SAR) [6, 8] computation at the edge server to locate the target RFID tag, as shown in Fig. 2(b).

2.3 RF-Based User Interface

When the user selects the target item, they have no knowledge of its hidden location. As a result, they may walk away from it or search in the opposite direction where the antenna cannot read the target RFID tag. To solve this problem, X-AR provides a dynamic RF-Based user interface that assists the user in searching.

2.3.1 UI during the Localization Process. X-AR sends UI feedback to the user based on measurements it has collected. First, when the SNR is low, it projects a red floating widget as in Fig. 2(c). When the user moves and X-AR gets higher quality RF measurements from the target tag, the widget turns blue to indicate improved proximity to the target. Secondly, X-AR can roughly estimate the general location of the target item after the first few measurements. Thus, X-AR visualizes its coarse initial estimate by showing a bright holographic ellipsoid in the region, as shown in Fig. 2(c). Although this rough estimated region is not enough to help the user retrieve the hidden item from a box, it helps them to walk towards the possible region and collect better RF measurements.

2.3.2 Item Retrieval. When X-AR has collected enough measurements to confidently locate the target item, it visualizes a green floating widget to tell the user that the item has been localized. X-AR then visualizes a green sphere as shown in Fig. 2(d) at the location of target item.

3 IMPLEMENTATION

We fabricated the antenna on a flexible substrate and mounted it on the visor of a Microsoft Hololens 2 AR headset. The antenna is connected via an SMA Cable to two Nuand BladeRF 2.0 Software Defined Radios controlled by a Raspberry Pi, similar to [6]. We implemented the EPC Gen 2 protocol [1] which allows X-AR to read and locate each RFID tag in the environment without receiving interference from other tags. The Raspberry Pi processes the received RF signals and sends channel estimates to an edge server over WiFi. The Hololens simultaneously performs visual inertial odeometry and streams its location over WiFi to the same edge server. The edge server performs the AR-based SAR, determines what visual cues to display on the RF-based user interface, and sends corresponding commands to the Hololens. The processing implemented is similar to [5, 6].

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