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Wi-Fi Can Read through Walls

Imagine this: you're lying on the couch in the living room watching TV, and then through the Wi-Fi in your house, you can know exactly the location of the things in the bedroom and what they look like. It sounds like telepathy, doesn't it? In a recent groundbreaking study, Professor Yasamin Mostofi's lab from the University of California, Santa Barbara introduced a novel method called Wiffract that made this possible. Hi, I'm Thomas Duan, the tech editor at Scientific American. Today, let's dive into this new technology.

But first, let's set the stage. When we hear Wi-Fi, we often think of how we connect to the internet to check emails, watch videos, or scroll on social media. However, Wi-Fi signals are much more than that. They are a kind of radio frequency wave, or RF wave, that fills our homes and they are invisible. Don't worry; this will not hurt your body, and we have been using these signals for communication for years. But the idea of using them to "see" or detect things is a relatively exciting, new concept for us. You may wonder why people don't use cameras, since nowadays it is even possible to manage that through our iPhones. That is because it is hard for cameras to work in dark environments and when the object is hidden by walls. So, reading by RF signals is a trending topic in research.

In researchers' world, these signals work pretty well in detecting body movements. For instance, researchers in Mostofi Lab published a technique in 2019 that can determine if the person walking behind the wall is the same as the one in video footage, by using only Wi-Fi signals. This innovative technique, known as XModal-ID, detects the unique movement patterns to identify walking people. One of the key strengths of this is that it neither requires any prior training data of the person being identified nor does it need prior knowledge of the operation area. Specifically, when a person moves, they can influence the reflection pattern of Wi-Fi signals in the area. This can be decoded to show information about the person's movement characteristics, which can match the video clip of the person walking. In the security and surveillance area, XModal-ID could be a game-changer, enabling non-invasive monitoring and identification of people in sensitive areas.

However, it is very difficult to detect objects that don't move. Taking XModal-ID as an example, the way it can detect people is to follow the change of the receiving Wi-Fi signal, which means if the person stands still in front of the antennas, the signals will not have any changes, making it hard to detect this person. Researchers have been working on this issue for years. Some have used millimeter-wave radars for this purpose, which is very expensive and difficult to implement. Some have used Wi-Fi to trace the signal that reflects back from the surface of the object, like how mirrors work. This can only generate blurry images that can only determine where the object is, but it is impossible to find out the shape of the object. Some researchers suggest that it might be possible to use deep learning or AI to help with this issue, but it would cost a lot of money and time to calculate. But now everything has changed. Researchers Anurag Pallaprolu, Belal Korany, and Yasamin Mostofi from the same lab have introduced a novel method called Wiffract, which uses the power of Wi-Fi signals to create images of objects including their shape. What's fascinating is that this method can also work for objects that are hidden behind walls, and this technology is solely based on math and physics and does not rely on deep learning or artificial intelligence.

So, how does it work? While former researchers claimed that using RF waves made it difficult to trace the object, this research shows that while using Wi-Fi signals, which have very low frequencies, the signals may not be as sensitive, let's say, as millimeter waves when reflecting on the object, which means RF imaging for Wi-Fi signals is a completely new path. After they discovered this, Mostofi, the professor of this research, said that they had taken a completely different approach to tackle this challenging problem by focusing on tracing the edges of the objects. Wiffract is based on the principles of Keller's Geometrical Theory of Diffraction. This theory, in simple terms, is about how waves—in this case, Wi-Fi signals—bend around corners and edges. In high school, we were taught that common objects are actually very rough although they may not touch like it. So when a Wi-Fi signal hits the edge of an object, it's not just reflected back like a mirror. Instead, it bends around these edges and corners, creating a unique pattern known as the Keller Cone. The shape and orientation of these Keller Cones vary based on the angle and characteristics of the object's edges. The cone then leaves different footprints, or traces of signals, on a given signal receiver. Through this theory, the researchers can find these traced edges, which can be combined to form a complete picture of the object. Just as Pallaprolu, the leading researcher said, "Tracing the edges is a compressive yet informative representation of the scene." Imagine a jigsaw puzzle, where each piece contains tiny information about an object's edges. When putting them together, they can reveal the shape.

This is completely different from the traditional methods. For example, if you remember, one traditional method uses AI to handle this. Through that method, people first need to create the scene. Then, they have to create a large dataset, normally more than a thousand records of data, with different objects in the scene, so that they can train the model with good accuracy. This would take months to complete, and once the scene is changed, for example, let's say you put a big new shelf in the room, all the work they've done will be lost, and they'll have to start the whole process over again. That's too complicated, isn't it? Wiffract, which we are talking about today, does not need this process at all, because it does not depend on AI, but only on mathematical and physical calculations. Also, compared to the method that uses millimeter waves, Wiffract only uses the most common RF signal around us, which is Wi-Fi. It is much cheaper and easier to construct, use, and maintain.

Wiffract's simplicity and effectiveness have been thoroughly tested. The researchers conducted 37 experiments in three situations: the first one was in an open area from all four sides, like a plaza. The second one was open from two sides, with the other sides having walls or other objects. The last one was in a room, where they built a wooden wall to let the object hide. The objects they chose are all alphabet-shaped and made of painted wood. The use of wooden materials can help Wi-Fi signals bounce back and shape the Keller Cones. For detection, the scientists first put three Wi-Fi antennas around the object. Two of the antennas were on the left and right sides, and the other was at the top front. These antennas could emit Wi-Fi signals to the object from different angles. Next, the researchers built a Styrofoam tower on a small cart, at the top of which were 6 receiving antennas. This cart was put between the object and the top-front antenna so that it could receive the Wi-Fi and send it back to the computer. The cart could move from left to right, and the antennas could move up and down. Thus, by moving it back and forth, we can receive the signals on a 2-dimensional surface, helping us to complete the image.

Now we received the signals, what should we do then? Well, the researchers made a mathematical model in the laptops to combine all the signals they received. You see, if we use a knife to cut a hollow cone, the cross-section it leaves behind will be an ellipse, or a curve at least, which is the shape the antennas would receive. The mathematical model could transfer those receiving curves into the lines of the edges they detected. To enhance the accuracy, the researchers also used a technique called Bayesian Information Propagation, which may be a more familiar term in the field of Statistics. Again, let's consider this as a jigsaw puzzle. If you are very confident about the place of one of the pieces, you can use it to put other adjacent pieces into the puzzle. Similarly, by identifying high-confidence edge points with their imaging, we could then propagate this information across the graph. This technique is particularly effective since the edges of an object are connected to each other. Thus, this can improve the image quality when some edges might be hidden or overshadowed by obstacles. ("Wiffract" 7) Then, our researchers used existing image-generation tools that have been used in the field of computer vision to reconstruct and show the completed image.

The results show that their method allows Wi-Fi signals to read for the first time, with an astonishing 86.7% accuracy when reading without walls. As described in the paper, "no other approach has produced results of this quality when imaging with only Wi-Fi." ("Analysis of Keller Cone" 6) When reading through the walls, researchers demonstrate an example where the signals can read the word "BELIEVE" when the objects are placed behind the walls, and the result can be accurately identified by their model. (“Wiffract” 10) Thus, they made it possible to use probably the most common signals to detect stationary objects.

This research has opened up new directions for object imaging, but it is essential to address the limitations of Wiffract. First of all, if you remember the process of the experiment, you may know that the receiving antennas have to move back and forth to gather all the Keller Cones created by Wi-Fi signals, which means the time it takes to detect the object is pretty long. Although it can be significantly faster than other RF imaging methods when we implement it, real-time imaging for Wiffract is impossible, limiting its applications in real life. What’s more, it’s worth mentioning that this technology can only detect the shape of the object, so it would be impossible for Wiffract to read printed pages. (Robinson) This might be a relief for people who are concerned about their phones being monitored remotely, but it also shows that Wiffract is not creating imaging as cameras do, but generating the shape of the object.

Looking forward, there are various ways to improve this technology. If you remember the situation when the object was hidden behind the wall, the wall they used was only a thin wooden board. So, detecting with thicker walls or more obstacles could be on the list of future experiments. Researchers claimed that they have mainly tested on alphabet-shaped objects only, so the detection and classification of everyday objects could be another future direction. It is possible to combine the existing image classifier to determine what the object is based on its shape automatically. Scientists also believe that this method might be generalized to a broader range of waves with low frequency, like acoustic waves, or sound waves. Talking about hardware improvements, the current detection setup is only for experiment development. Integrating this technology with smart devices is one possibility to make it useful in daily life.

The potential of the application is unlimited for Wiffract. It can be implemented in smart homes, which means it helps you find missing items or monitor your living space for security. ("Wiffract" 1) Compared to Airtags, the use of this technology is also available for Android users, and people without Bluetooth devices can also locate their items in their homes. Additionally, imagine a world where the rescue squad, equipped with Wi-Fi imaging devices using Wiffract, can quickly find people trapped in disaster areas after earthquakes and tornados. Traditional methods for search and rescue teams to locate the victims include sound detection devices, trained dogs, and on-site engineering assessments. (European Centre 14) In comparison, Wiffract could significantly speed up navigation, as it doesn't require physical penetration into the debris and can potentially identify people trapped under rubble more quickly and accurately.

On the other hand, some experts are concerned about the ethical dimensions of this technology, especially regarding privacy and data security. They are concerned that cyber-criminals could use this technology to locate valuable items inside people's homes remotely. This could lead to targeted burglaries, which can cause not only financial but also emotional damages, as the sense of security in one's home is destroyed. Router companies should also ensure the privacy of their customers' information when implementing Wiffract in their smart home devices in the future. While the scientists from UCSB did not discuss the privacy implications of Wiffract, balancing the benefits with these concerns is crucial as we step into an era where the invisible waves could become the eyes around us. It's essential to ensure the responsible use of this technology for legitimate purposes. (Maruccia) This could include requiring permissions for using Wiffract in residential areas or developing devices that limit the depth of penetration.

But for sure, as we continue to explore Wiffract under proper regulations, it's clear that this innovative technology, based on the principles of Keller's Geometrical Theory of Diffraction, offers new possibilities in imaging and sensing that can go far beyond the scope of traditional methods. Wiffract isn't just a scientific breakthrough in the field of RF imaging, but it can inspire future innovations to make the invisible seen, bringing new solutions to longstanding problems. For Scientific American, I'm Thomas Duan. Thanks for your listening, and talk to you next time.