2022
THE JOURNAL ON
TECHNOLOGY AND
PERSONS WITH
DISABILITIES

Outdoor Navigation Assistants for Visually Impaired Persons: Problems and Challenges

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Abstract

This article explores the problem of building outdoors navigation assistants for persons with visual impairment (NAVI). A review of the state-of-the-art solutions and frameworks of navigation assistants for persons with visual impairment shows that, although several solutions have been proposed, the functionality of such systems is often limited to obstacle detection and navigation assistance based just on satellite positioning information presented to the user in limited forms. Navigation assistants available to final users are basically the same Global Navigation Satellite System (GNSS) widely available to everyone else, adding little to meet the necessities of users with visual impairment. We present the requisites of building a NAVI system running on smart glasses integrating all journey stages and exploiting the current technology to its full potential. Accordingly, we identify key technology gaps and areas that need further research to deliver a system with such features.

Keywords

Visual impairment; Blindness; Wayfinding; Smart Glasses; Computer Vision; Electronic Mobility Aid

Introduction

Persons with visual impairment are one of the most affected by the lack of accessibility. Approximately 2.2 billion people with visual impairment in the world (World Health Organization 2021) have difficulties in engaging in activities that involve social relations, which affects their process of socialization (Slade and Edwards 2015). Transportation is one of the greatest barriers and a major challenge for persons with visual impairment. Only a minority of the persons with visual impairment report being confident using public transport according to The Royal National Institute of Blind People UK (RNIB) (Pavey et al. 2009). Autonomous mobility is affected not only by transport availability, but also by difficulties in walking outdoors, including crossing streets and locating the final destination. People commonly stumble across road signs and architectural barriers (Pavey et al. 2009).

Wayfinding is a complex and interwoven task that must be broken down to be fully understood. The British RNIB Wayfinding Project (Worsfold and Chandler 2010) defines the journey stages as walking, catching a transport (bus, train, tube, ferry, plane), and navigating within a building. Walking is the most important stage that binds the other journeys stages together, yet it is the one with the least amount of information or assistance. These stages are further refined into activities and actions following four principles of wayfinding: getting information and using it, orientating within the environment, navigating within the environment, and entrance and exit identification.

Historically, canes and guide dogs are the most widely used tools for detecting obstacles by persons with visual impairment (Pavey et al. 2009). Nonetheless, both options fail to detect obstacles over the knee level or beyond a 30 cm to 60 cm range. Such obstacles cannot be detected before they are dangerously close to the person. Some other tasks, such as identifying buildings, shops, buses, entrances, signs, and written information, are hardly possible without the assistance of an electronic device or a person with no visual impairment.

Many studies have been conducted to develop equipment and technology to assist autonomous navigation of persons with visual impairment. Navigation Assistance for Visually Impaired (NAVI) refers to systems that guide or assist persons with vision loss through sound commands (Aladrén et al. 2016). Table 1 describes the main systems available, primarily focusing on their equipment, features and limitations. Most of the systems found in the literature focus on the detection of obstacles. Few solutions have been proposed to improve the outdoors mobility and safety of persons with visual impairment. In general, the user needs to carry complex hardware systems and, in some cases, the environment where the navigation must be accomplished also has to be prepared beforehand. The most comprehensive solutions involve connecting users to remote agents (Wiberg 2015; Kanuganti 2015). Although remote human assistance can be versatile, disclosing what users are seeing or doing to remote agents can be undesirable and embarrassing. Users report that they do not feel safe to disclose where they are going to strangers, neither in person nor in a video call (Avila et al. 2016; Williams et al. 2013). It further raises privacy and legal concerns since agents and users may be in different jurisdictions with different mores. For these reasons, we do not consider using remote human assistants as viable for autonomous navigation.

Table 1. Overview of NAVI Systems Including Main Features and Equipment Used.

System	**Equipment**	**Obstacle detection**	**Object identif.**	**Indoor path**	**Outdoor path**
(Kanuganti 2015)	Smartglasses, smartphone, camera, GNSS, remote human agent	Yes	Yes	Yes	Yes
(Wiberg 2015)	Smartphone, camera, remote human agent	Yes	Yes	Yes	Yes
(Ran et al. 2004)	Computer, GNSS, Wi-Fi, sonar	Yes	-	Yes	Yes

System	**Equipment**	**Obstacle detection**	**Object identif.**	**Indoor path**	**Outdoor path**
(H.-C. Wang et al. 2017)	RGBD camera, computer, haptic	Yes	Yes	-	-
(S. Wang et al. 2014)	RGBD camera	Yes	Yes	-	-
(Li et al. 2016)	Tablet, RGBD camera	Yes	-	Yes	-
(Dreamwaves 2021)	Smartphone, GNSS, camera	Yes	-	-	Yes
(Katz et al. 2012)	Computer, GNSS, stereoscopic camera, motion tracker	Yes	-	-	Yes
(Mayerhofer et al. 2008)	Computer, mobile phone, GNSS, infrared, dead reckoning device	Yes	-	-	Yes
(Koley and Mishra 2012)	GNSS, sonar	Yes	-	-	Static
(BlindSquare 2012)	Smartphone, GNSS, compass, Bluetooth	-	-	Yes	Yes
(Wayfindr 2017)	Smartphone, Bluetooth	-	-	Tube	Tube
(Agrawal et al. 2017)	Sonar, GNSS, GSM	Yes	-	-	-
(Aladrén et al. 2016)	RGBD camera, infrared, RFID	Yes	-	-	-
(Float 2016)	Smartphone, camera	Yes	-	-	-
(Ifukube et al. 1991)	Sonar	Yes	-	-	-
(Ju et al. 2009)	Computer, camera	Yes	-	-	-
(Kanwal et al. 2015)	RGBD camera, infrared	Yes	-	-	-
(Kulyukin et al. 2005)	Computer, RFID, sonar	Yes	-	-	-
(Mahmud et al. 2014)	Sonar	Yes	-	-	-
(Mandal 2018)	Sonar, infrared	Yes	-	-	-
(Nandhini et al. 2014)	GNSS, RFID, sonar	Yes	-	-	-
(Tapu et al. 2014)	Camera	Yes	-	-	-
(Wahab et al. 2011)	Sonar, water detector	Yes	-	-	-
(OrCam 2013)	Wearable camera	-	Yes	-	-

System	Equipment	Obstacle detection	Object identif.	Indoor path	Outdoor path
(Ahmetovic et al. 2016)	Smartphone, Wi-Fi, Bluetooth	-	-	Yes	-
(Chaccour and Badr 2015)	Smartphone, Bluetooth, Wi-Fi, surveillance cameras, head marker	-	-	Yes	-
(Fusco and Coughlan 2020)	Smartphone, camera, gyrocompass	-	-	Yes	-
(Jain 2014)	Smartphone, RFID	-	-	Yes	-
(Mehta et al. 2011)	RFID, Bluetooth, compass	-	-	Yes	-
(Nassih et al. 2012)	RFID	-	-	Yes	-
(Öktem et al. 2008)	RFID, compass	-	-	Yes	-
(Right-Hear 2015)	Smartphone, Bluetooth	-	-	Yes	-
(American Printing House for the Blind 2013)	Smartphone, GNSS	-	-	-	Yes
(Brusnighan et al. 1989)	GNSS	-	-	-	Yes
(Ciaffoni 2011)	Smartphone, GNSS	-	-	-	Yes
(Espinoza and González 2016)	Smartphone, GNSS, compass	-	-	-	Yes
(EveryWare Technologies 2013)	Smartphone, GNSS	-	-	-	Yes
(Garmin 2011)	Smartphone, GNSS, compass	-	-	-	Yes
(Humanware 2017)	GNSS	-	-	-	Yes
(Kaminski et al. 2010)	Computer, GNSS, compass, gyrocompass, keyboard	-	-	-	Yes
(Kirkpatrick and Lilburn 2004)	Smartphone, GNSS	-	-	-	Yes
(Liu et al. 2015)	Smartphone, GNSS	-	-	-	Yes
(Loomis et al. 2005)	Computer, GNSS, compass	-	-	-	Yes
(Novartis Pharmaceuticals 2014)	Smartphone, GNSS	-	-	-	Yes
(OsmAnd 2010)	Smartphone, GNSS, compass	-	-	-	Yes

System	Equipment	Obstacle detection	Object identif.	Indoor path	Outdoor path
(Petrie et al. 1996)	Handheld computer, mobile phone, GNSS, compass	-	-	-	Yes
(Pielot et al. 2010)	Smartphone, GNSS, compass	-	-	-	Yes
(Sendero Group 2002)	GNSS	-	-	-	Yes
(Sendero Group 2013)	Smartphone, GNSS	-	-	-	Yes
(Snigle 2016)	Smartphone, GNSS, compass	-	-	-	Yes
(Swis Federation of the Blind 2012)	Smartphone, GNSS	-	-	-	Yes
(Transition Technologies 2013)	Smartphone, GNSS	-	-	-	Yes
(Lakehal et al. 2020)	Smartglasses, smartphone, GNSS	-	-	-	Static
(Tashev et al. 2018)	Smartphone, camera	-	-	-	Static
(Dharani et al. 2012)	RFID	-	-	-	-
(Gulati 2011)	GNSS	-	-	-	-
(Hub and Schmitz 2009)	Tablet, GNSS, RFID, inertial sensor	-	-	-	-

The motivation for this paper arose from open discussions with persons who are blind or visually impaired. It became evident that, despite a large number of NAVI systems presented in the literature, for most people they were unviable (Real and Araujo 2019; Griffin-Shirley et al. 2017). Thus, systems were being created to solve problems that did not exist. There is still a need for a solution that integrates all outdoors journey stages. Therefore, we posit a model of NAVI system for outdoors navigation exploiting the current technology to their full potential. In this way, we can understand the pitfalls involved in developing such a system.

Discussion

We first present the desired features and user interface of a NAVI system for outdoors navigation. Next, we consider the equipment and sensors currently available that could make it possible to build a system with such features. This leads us to identify key technology gaps and areas that need further research.

Features and User Interface

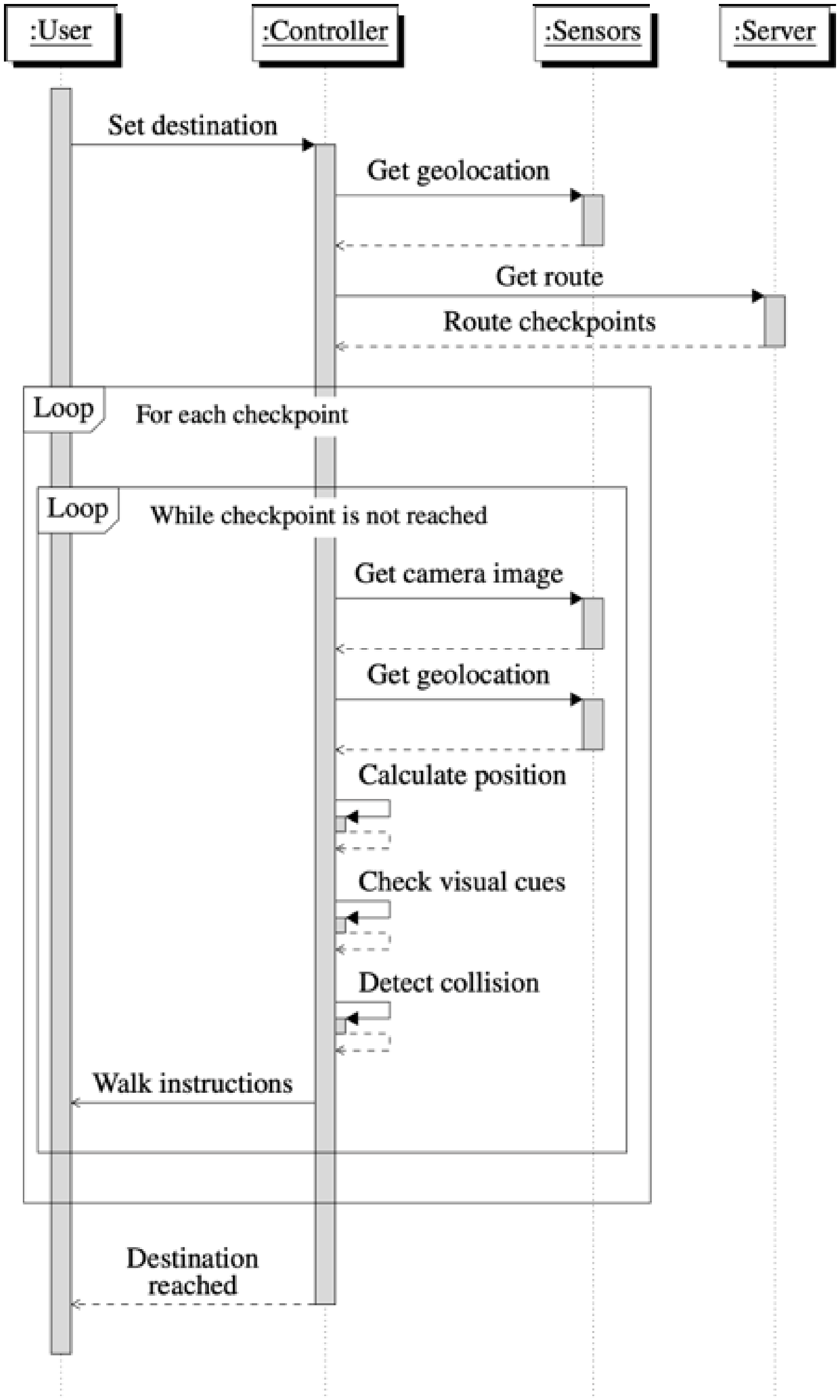

Fig. 1. Model of NAVI Systems.

Figure 1 shows a sequence diagram for the tasks of outdoors visual navigation. First, when the user requests assistance to reach a destination, the system (controller) must retrieve the user geolocation and request a route to the online server. An internet connection allows making use of more complex algorithms and access to services such as the Google Directions API and the Apple WebKit for up-to-date information about maps, roads, sidewalks, and available routes (Google Inc. 2021; Apple Inc. 2021). Nevertheless, local processing is preferred when possible.

The evaluation of possible routes must consider: (1) time and length of journey, (2) accessibility and safety of the path, well signposted and paved, (3) easy access to public transport like bus, tube, train, and tram, and (4) roadworks and closed ways. The route retrieved from the server is segmented, and checkpoints need to be reached in sequence to arrive at the destination.

The route segments and checkpoints need to be carefully chosen. A segment that involves crossing a street, for example, must be broken down into more specific steps: “approach the pedestrian crossing,” “activate pedestrian traffic light,” “cross the street” and “reach the sidewalk.” These steps are usually implicit for persons with sight, yet they are essential to allow autonomous journeys of persons with visual impairment. It is not just about giving more instructions; the quality of instructions is essentially different. Even when the same route is followed by persons with and without visual impairment, the instructions must consider the individual necessities of each user.

For each checkpoint on the route, the system guides the user by audio and keeps estimating the user position in real-time, evaluating whether they are on track or the route needs to be recalculated. The camera allows identification in real-time of obstacles and assesses imminent collision risk. In a scenario of crossing a street, for example, the camera allows the identification of pedestrian crossings, traffic lights, cyclists and cars to decide when it is safe to cross. The system also identifies and prioritizes recognized text to announce relevant information considering the context. A big sign far away may be less relevant than a small street sign near the user. With no priority classification, the user may be overwhelmed by irrelevant announcements.

The walk instructions are given both by spoken and audible signals. The audio feedback must not block signals from external sources, which helps in keeping the safety of users. With the use of smart glasses, users may receive audio instructions to aim their head towards locations where they expect important visual targets. In this way, there is no need to train users beforehand. A heads-up display may be used by persons with low vision, enabling announcements both by audio and on the display. Yet, the use of a display is secondary and is not in any way essential.

The use of non-visual references is fundamental when giving navigation instructions. Simple instructions such as “walk 20 m” are hard to follow because it refers to a measure not easily verifiable in such a situation. Alternatively, saying “walk twenty steps” is more intuitive and easily verifiable. Although it is not as accurate, checking the user’s position in real-time allows route correction and follow up instructions such as “walk two more steps” or “you have reached the street corner, turn left now.”

When the destination is finally reached, the system learns the user’s preferences considering the journey actually undertaken. The more people use it, the better it would get at suggesting convenient routes to everyone.

Equipment and Sensors

Localization technology is the backbone of navigation systems. Currently, the Global Navigation Satellite System (GNSS) is the main technology used for outdoors navigation. GNSS is a general term for any satellite constellation providing positioning and navigation services on a global or regional basis. While the United States' GPS is the most prevalent GNSS, other nations have also fielded their systems to provide independent or augmented services: GLONASS (Russia), BeiDou (China), Galileo (European Union), NavIC (India) and QZSS (Japan).

Although GNSS is a global solution for geolocation, there are some challenges to using them on NAVI systems. Their horizontal accuracy of approximately 10 m (U.S. Air Force 2014) makes it impossible to safely guide a pedestrian with acceptable precision. The error range increases when the GNSS signal is blocked by large objects such as trees, bridges and buildings. In places with many obstructions, such as metropolitan areas or inside buildings, these structures can block satellites' signals to an extent that the receiver is not able to calculate its position.

Some methods have been proposed to increase the accuracy of GNSS receptors, including Differential GPS (DGPS), Assisted GNSS (A-GNSS) and satellite-based augmentation systems (SBAS). Nonetheless, these augmented solutions are currently restricted to niche applications for reasons of practicality and cost.

Digital cameras are cheap, compact, easy to maintain, and widely available on smartphones and laptops. When associated with computer vision algorithms, it becomes possible to perform tasks such as reading signs, labels, texts, identifying color information, objects, people, or cash. Although distinguishing between close and far objects with a single camera is possible, this task is not trivial. Usually, other devices are used to accomplish this task, e.g., stereo or RGBD cameras; ultrasonic, Bluetooth or infrared sensors.

Computer vision algorithms have been advancing since the last decade. Complex algorithms can now run in real-time on smartphones and wearable devices. Computer vision algorithms are easier to reproduce and less biased on interpreting real scenes when compared to humans. Nevertheless, the current error rates are still higher than that made by humans with sight, which becomes a large practical problem posed by using computer vision to interpret the visual environment. As a result, the user interface of any NAVI system needs to accommodate the inevitability of such errors.

Few solutions exploit the potential of computer vision algorithms. OrCam (2013), for example, aims to recognize labels, products, text, and other objects close to the user. Images captured by the camera may be combined with GNSS information to not just precisely localize the user in real-time, but also to know what direction they are heading to. In 2019, Google announced a Visual Navigation System incorporated on Google Maps app available on selected locations (Reinhardt 2019). Although it is not specifically designed to have persons with visual impairment in mind, they use computer vision algorithms to match images taken in real-time from the user's smartphone with a data set to improve their geolocation estimation. The path is then shown on the screen using augmented reality.

Computer vision algorithms rely on visual appearance to detect obstacles and objects. Therefore, they are sensitive to factors that change visual appearance, e.g., illumination, point of view, artefacts, and occlusion. Internal factors as processing power and trained model also affect accuracy. Some classes of objects are well studied and present a high detection accuracy, but some others need more study and large image data sets for training purposes.

Ultrasonic sensors are common components on outdoors NAVI systems. Sound propagation is used to measure the distance to objects in a short-range from 2 cm to 400 cm (Adafruit Industries LLC 2020). They are cheap components that do not need the preparation of the environment in advance. Although ultrasound pulses propagate in three dimensions, the distance information is unidimensional. It is possible to combine sensors pointing in different directions, but this approach can be problematic for tasks other than roughly detecting obstacles.

Yet, it is still not possible to detect long-range distances or the shape of objects. When used on NAVI systems, ultrasonic sensors help to avoid obstacles but need to be somehow attached to the main processing device, as it is not usually embedded on laptops, smartphones or smart glasses.

Other sensor components, such as Bluetooth and infrared beacons, are undesired for outdoors use because they require preparation of the environment beforehand.

Technology Gaps

Table 2. Features of the NAVI Model for Outdoors Navigation.

Feature	**Development**	**Solved?**
F1: Localize user with high accuracy	Current accuracy is approximately 10 m with GNSS (U.S. Air Force 2014). Maximum required error is 0.5 m	Partially
F2: Calculate the best route to reach a point of interest	Pedestrian routing is freely available on smartphones map apps (Apple Inc. 2021; Google Inc. 2021)	Yes
F3: Define micronavigation instructions	Further studies needed on Human Computer Interface (HCI) (Budrionis et al. 2020)	No
F4: Recognize public transport vehicles	Solved by Computer Vision detection and classification algorithms	Yes
F5: Locate doors and entrances	Solved by Computer Vision algorithms with 97.96 % accuracy (Othman and Rad 2020)	Yes
F6: Recognize relevant signs and labels	Partially solved by Computer Vision detection, classification and OCR algorithms (OrCam 2013)	Partially
F7: Identify the sidewalk	Solved by Computer Vision segmentation algorithms (Olvera et al. 2020)	Yes
F8: Access collision risk	Solved by Computer Vision algorithms	Yes
F9: Perform visual navigation	Further studies needed on Computer Vision (CV)	No
F10: Interact with the user in a natural and intuitive way	Further studies needed on Human Computer Interface (HCI) (Budrionis et al. 2020)	Partially

Table 2 summarizes the desired features of an outdoors NAVI system mentioned so far and highlights their current development status reported in the literature.

The first task in Table 2 is to localize the user with high accuracy (F1). Although there are some subtleties in certain scenarios, it is a standard task, so we have marked it as such. Although GNSS provides only around 10 m accuracy, that is either sufficient for many purposes (e.g., ship navigation) or can be combined with tracking models to give improvements. For example, in autonomous vehicle navigation, systems assume that the vehicle is located on the road using an up-to-date map. Thus, cross-track errors can be zeroed. Pedestrian navigation is more challenging because people roam off streets, but with good tracking and with newer GNSS components such as Galileo and SBAS systems such as WAAS and EGNOS, it is reasonable to assume that determining outdoor pedestrian geolocation might be solved to within 1 m. Indoor navigation will either require significantly greater antenna gain at the receiver using larger and more complex receptors, or widescale deployment of indoor GNSS augmentation systems. Both seem unlikely within the next ten years. Hence are other “partially” ratings.

Calculating the best route (F2) can be considered solved for outdoors pedestrian navigation. Google and Apple services provide pedestrian routing freely available online and with vast documentation (Apple Inc. 2021; Google Inc. 2021). These services consider factors such as time, walking distance, accessibility, and roadworks. Defining the micronavigation instructions (F3), on the other hand, remains a challenging open problem. The route segments retrieved from online routing services must be broken down into more specific segments. Navigating in large open spaces, in a park for example, is hardly a problem for persons who are sighted. Persons with visual impairment may get lost or go astray without accurate navigation instructions and constant rerouting assessment. Furthermore, there is every reason to think that instructions need to be personalized since visual disabilities are diverse.

Recent advances in computer vision make viable the recognition of vehicles (F4), doors (F5), signs (F6) and sidewalk (F7) with high accuracy. Recognition of labels using Orcam MyEye and Seeing AI, for example, is reported to achieve greater than 95% accuracy in text recognition for flat, plain word documents (Granquist et al. 2021). Recent research has been conducted on detecting signs specifically for navigation of persons with visual impairment (Cheraghi et al. 2021). When the recognition is associated with the tracking of objects, it becomes possible accessing collision risks in real-time (F8) with no need for extra sensors.

Despite notable improvements in visual recognition, performing visual navigation (F9) remains a very significant problem for NAVI systems. Current solutions involve building 3D maps a priori (Dong et al. 2020), which is not desirable in outdoors navigation. Even if the user position could be calculated with enough accuracy, the information retrieved by the camera and processed by computer vision algorithms still needs to be classified and organized into instructions to the user. This is the basis for naturally interacting with users (F10).

It is important to recognize that this paper is written from the traditional research perspective, which focuses on the lower Technology Readiness Levels (TRLs 0 to 4). It goes without saying that to be useful, all research needs pushing to higher TRL levels, which requires commercial or government investment.

Conclusions

In this article, we explored the problem of building outdoors navigation assistants for persons with visual impairment. A review of the state-of-the-art solutions and frameworks of navigation assistants for persons with visual impairment showed that, although several solutions have been proposed, the functionality of such systems is often limited to obstacle detection and navigation assistance based just on GNSS. Navigation assistants available to final users are the same satellite navigation system widely available to everyone else, adding little to meet the needs of users with visual impairment.

We presented the requisites of building a NAVI system running on smart glasses integrating all journey stages and exploiting the current technology to its full potential. Finally, we highlighted the areas that need further research and the problems that need to be solved to make such a system viable. In subsequent work, we will zoom in on these technological lacunae and show how a NAVI system could soon be a practical reality.

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