Clew Maps: Crowdsourcing Routes for Indoor Navigation

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***Abstract*—Clew Maps reimagines Clew as an app that crowdsources routes for indoor navigation and repurposes the existing backend code base to better serve this purpose by alleviating the pain points inherent to the current route-sharing mode of use. By implementing image anchoring to improve the robustness of the anchoring and alignment process, and by using a cloud database for route storage along with a new user interface (UI) to address the limitations of sharing routes in Clew, Clew Maps makes independent travel in unfamiliar public spaces more accessible for people with blindness and visual impairments (B/VI).**

I. Introduction

The Clew app for indoor navigation, using Apple's ARKit augmented reality (AR) framework, combines device motion tracking, camera scene capture, and a trail of virtual breadcrumbs throughout the route to track a user's location in space [1]. Clew does not use GPS location tracking; instead, the entire route is recorded relative to the starting pose of the phone (known as the anchor point of a route). Thus, when re-navigating a saved route, it is crucial for the user to align their phone in the same position and orientation as the anchor point in order to navigate the route accurately.

The route sharing feature of the Clew app, as it currently exists, is underutilized for several reasons identified through user interviews: it is difficult to communicate the location of an anchor point asynchronously, the alignment process to an anchor point is error-prone, and route sharing is done one local route at a time, from one device to another. Clew Maps addresses the first two pain points by introducing a new image-based method for creating and aligning to anchor points, and introduced cloud storage for routes and built new user interfaces to alleviate the last pain point.

Clew Maps aims to address the lack of availability of indoor maps for people who are B/VI, which is one of the areas in which there is a large information gap that hinders their ability to independently travel to unknown and unfamiliar spaces [2]. Clew Maps is designed for use in public spaces with confusing layouts that users are generally unfamiliar with, such as hospitals and transport hubs. The app is integrated with Apple's App Clips, which are lightweight versions of an app that isolate a specific functionality of the full app into a format that can be downloaded quickly onto the user's phone by scanning an invocation URL, which links a specific website domain to a single app. The goal of Clew Maps is to create a network of indoor maps of public spaces that can be seamlessly downloaded onto a device and used to navigate independently to unfamiliar destinations.

II. Methods

A. Physical Anchoring

In order to make anchor creation and route alignment more robust for Clew Maps, the anchoring process was reworked to rely on an image's fixed location in physical space rather than the pose of the user's phone in physical space. When saving a route's anchor point, Clew uses ARKit to return a 4x4 rotation matrix of the phone's yaw relative to the global coordinate system. When the user realigns their phone to that anchor point to navigate a saved route, another rotation matrix representing the phone's yaw in the global frame is returned. By using Equation 1, the phone navigating the saved route is aligned in the frame of the phone that recorded the route with yaw correction. Multiplying the rotation matrices R creates a transform that corrects for yaw offset between the anchor creation and route alignment. The resulting transform is used for the change of basis from the alignment frame to the anchoring frame. In the following equations, the route creation frame is abbreviated as c, the global frame as g, and the route alignment frame as a. In this notation, R_a^b is interpreted as "the transform matrix used for the change of basis from a to b."

$$R_g^c(R_g^a)^{-1} = R_a^c \tag{1}$$

The primary problem that arose from Clew's method of anchoring was the reliance on the user aligning their phone in the same anchoring position each time they navigated a saved route, since these transforms could only account for offset in the yaw of the phone. Since the entirety of a saved route is relocalized according to the starting anchor of the route with little adjustment thereafter, poor alignment at the beginning of the route due to user error can noticeably exacerbate the drift, and thus precision, of the navigation. Furthermore, for shared routes, asynchronously communicating the proper anchor pose of the phone was a barrier that increased the difficulty of using shared routes effectively and safely.

In lieu of the phone pose acting as the physical anchor point that persisted across multiple navigation sessions, Clew Maps uses ARReferenceImage objects placed in the environment to align users to saved routes. An ARReferenceImage is a fixed 2D image with a known size, hard-coded into the assets of Clew Maps, whose position and orientation in the physical environment can be detected by ARKit as shown in Fig 1 [3]. The use of ARReferenceImages relies on the assumption that these images remain stationary in the global coordinate system between route creation and route navigation. By using ARReferenceImages, an added burden is placed on an individual to correctly establish and maintain these physical images in a space, which we plan to investigate as we begin pilot testing in public spaces.

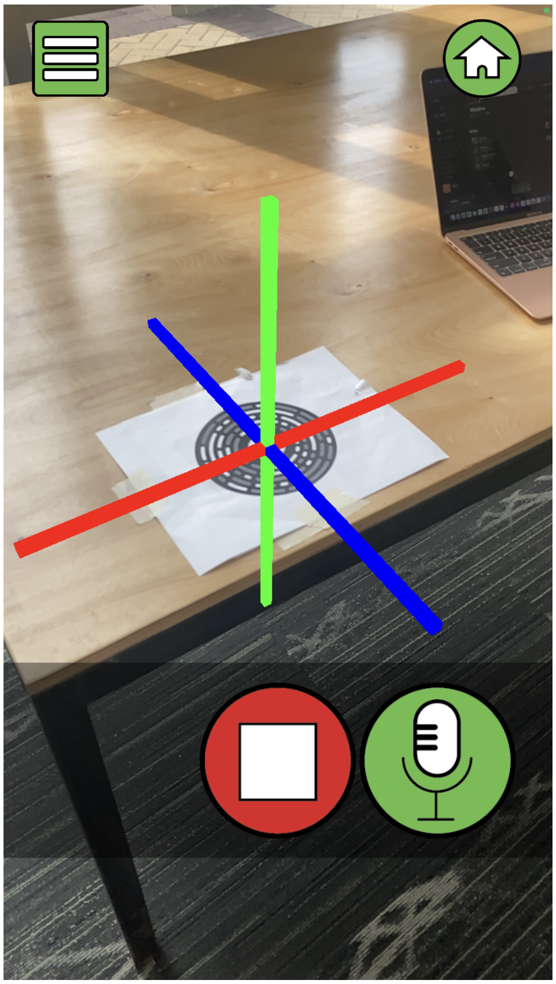

Figure 1. An example of an ARAnchor on an app clip code. The axes are superimposed on the image in AR, demonstrating the ability of ARKit to detect the position and orientation of 2D objects in physical space.

Because the ARReferenceImages have a fixed pose in the global coordinate system that can be detected by ARKit as an ARImageAnchor, they essentially replace the role of the global frame in the processes of anchor creation and route alignment. Equation 2 shows the new transformation matrix that results from the alignment process used in Clew Maps. The resulting transformation matrix T captures differences in position and orientation in the phone's pose between anchor creation and route alignment, resulting in a more robust localization as compared to Clew. The image anchor's coordinate system is abbreviated as i.

$$T_i^c (T_i^a)^{-1} = T_a^c \tag{2}$$

B. Codesign

Throughout the summer research period, interviews with people living with B/VI, along with orientation and mobility (O&M) specialists and people who manage physical spaces primarily used by B/VI people, were conducted both in-person and over Zoom video chat. TestFlight was used to distribute beta versions of Clew Maps, after which focus groups, feedback sessions, and targeted individual interviews were conducted to gather qualitative data about using the app. Quantitative data in the form of images from the phone's rear-facing camera and telemetry from the phone's sensors is also gathered on devices running TestFlight builds, although detailed analysis of this data has yet to take place.

C. UI and UX Design

The potential for the route-sharing functionality in the Clew app is currently hindered by the unintuitive user interface and difficulty in discovering and using routes shared by others. Clew Maps addresses this by using Firebase, a cloud database, as a repository of saved routes that can be shared among devices, and features redesigned user interfaces to better facilitate the uploading and downloading of saved routes.

Instead of saved routes being stored locally on an individual's device and being shared user-to-user, the starting anchor point of each route is associated with a unique 3-digit app clip code ID. Each of these codes maps to a specific location in physical space, i.e. an ARReferenceImage or app clip code. In this way, multiple routes can all be linked to an app clip code ID, provided that they all share the same ARReferenceImage or app clip code as their starting anchor. When a route is uploaded to Firebase, the information is sent to two locations: the identifiers file for that app clip code ID and the Clew route data file for that specific route (see the right side of Figure 2). The identifiers file is a JSON listing all the routes that start from a common app clip code ID, specifically a list of dictionaries where the keys are unique route IDs and the values are the corresponding route names. The route ID number maps to the location of its Clew route data file on Firebase, which contains the data needed to reload a route, e.g. the transform of phone relative to ARImageAnchor, navigation waypoints, and breadcrumbs of path.

The workflow for discovering available shared routes and downloading them locally to a user's device was also reworked with a new UI to complement an improved user experience (UX). Whereas Clew loaded routes directly to the Saved Routes List in the app, requiring the user to enter a new section of the app to begin navigating a route, Clew Maps automatically displays a list of route names that share an app clip code ID and thus a starting anchor point based off the app clip code ID. The user can select any one of these routes to navigate based on their known starting location in physical space, and the selected route name will map to the unique

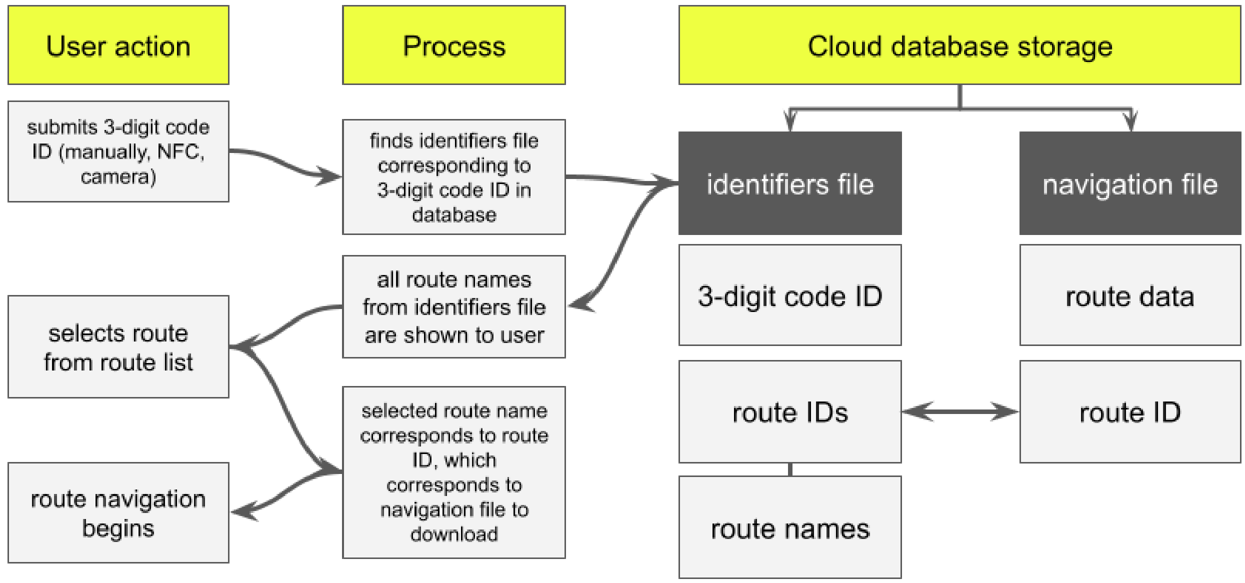

Figure 2. This figure shows the hypothesized workflow for downloading shared routes from Firebase.

route ID, which automatically locates and downloads the corresponding navigation file from Firebase and prompts the user to localize off the ARReferenceImage. This UI minimizes the number of times a user must click, or select a button, before beginning route navigation. Furthermore, the user's physical location is built into the route selection process, eliminating the need for them to track the starting location and orientation of a large repository of locally saved routes, making Clew Maps more robust against user error.

In the future, the user will also be able to scan an app clip code or NFC tag containing an invocation URL with their phone, automatically downloading the Clew Maps app clip. The list of routes will automatically load based on the app clip code ID that is queried from the invocation URL, and the user can select the route to navigate, localize off the ARReferenceImage, and navigate independently to their destination. By making full use of app clips and their ability to quickly, automatically, and temporarily download a core functionality of a full app to a device, we hope to lower the barrier of entry and introduce another avenue to discovering Clew.

III. Discussion

In user interviews, we observed that locating the ARReferenceImage in space was often a barrier for people who are B/VI, especially when little instruction and few non-visual cues were given about where or how to position the phone camera to successfully align to the anchor. Subjects also reported that tapping an NFC tag was a more successful way of invoking the app clip, as opposed to purely visual methods such as correctly aligning the rear-facing camera to a QR or app clip code. Based on this feedback, it is clear that alternative, non-visual methods (such as audio beacons or tactile images) of invoking the app clip and aligning the phone camera merit further investigation in order to improve the UX, particularly for people who are B/VI.

The exploratory area of route discovery must also continue to be fleshed out, as the travel planning needs of people who are B/VI differ greatly from sighted individuals when visiting unfamiliar locations [2]. This need was reflected in the feedback as a desire to know about shared routes through Clew Maps in a space before physically arriving there (i.e., during the trip planning phase), such as being able to download Clew Maps routes through the website of a point of interest. Another idea that was brought up during an interview was an online database listing not only the points of interest that had Clew Maps routes, but also the number of routes in each location. Both these sentiments reflect the need to investigate methods of communication to B/VI individuals during the trip planning phase to build confidence and trust.

IV. Conclusion

The lack of indoor maps is a major barrier to the ability of people who are B/VI to navigate independently, safely, and confidently. Built off the proven framework of the Clew app for indoor navigation, Clew Maps leverages a new method of image anchoring and a route repository stored in the cloud to alleviate the existing pain points of route sharing in Clew. Based on beta testing with users, continued research into the app discovery and route alignment processes should take place, particularly in the context of requirements for accessible journeys to unknown settings for people who are B/VI.

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REFERENCES

[1] C. Yoon, R. Louie, J. Ryan, M. Vu, H. Bang, W. Derksen, and P. Ruvolo, "Leveraging augmented reality to create apps for people with visual disabilities," *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*, Oct 2019.

[2] C. Engel, K. Müller, A. Constantinescu, C. Loitsch, V. Petrausch, G. Weber, and R. Stiefelhagen, "Travelling more independently: A requirements analysis for accessible journeys to unknown buildings for people with visual impairments," *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*, Oct 2020.

[3] "Arreferenceimage." [Online]. Available: https://developer.apple.com/documentation/arkit/arreferenceimage