Clew Maps: Cloud-Based Route Sharing and iOS App Clips for Indoor Navigation

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Abstract

Clew Maps is an update to a preexisting iOS App for indoor navigation called Clew. Presently, blind and visually impaired (BVI) individuals struggle to navigate unfamiliar spaces, and often have to rely on navigation instructions from a sighted guide. Clew Maps introduces a cloud database that can store pre-recorded routes that users can navigate along in an App Clip experience. This means that even non-Clew users can utilize the navigation tool without downloading the app, and that routes can be navigated by an individual without them having to walk along the route to record it ahead of time. Clew Maps robustly anchors the device utilizing ARKit's ARImageAnchors; however, more work is required to better understand the potential use cases and address potential pain points for BVI individuals, such as route discovery and aligning to image anchors.

Introduction

Navigating to unfamiliar spaces presents considerable challenges for individuals who are blind or visually impaired (BVI). BVI individuals employ a wide variety of orientation and mobility (O&M) skills and tools such as white canes, guide dogs, and phone apps; however, many BVI individuals still must ask for help from others more often than they would prefer in unfamiliar spaces that are not accessible [2].
In 2020, Apple released App Clips in iOS 14, which are lightweight versions of apps that a user can launch through an invocation such as scanning a QR code, near field communication (NFC) tag, or clicking a link. In addition to launching faster than a conventional app due to their small size, a single App Clip can support multiple experiences depending on the specific invocation URL that is used to launch the App Clip [1]. Invocation URLs are parsed and used to present varying information depending on the context of the user. App Clips have significant potential for navigation apps, since the act of opening an App Clip experience instantaneously localizes the user to a relatively small possible radius, which is especially small for NFC invocations.
This paper introduces the Clew Maps app and associated App Clip for uploading and accessing routes to and from an external database. This work builds on the navigation and localization techniques developed for Clew, an iOS app that allows users to record routes indoors and navigate along them. Clew relies on visual-inertial odometry within Apple's ARKit in order to store location breadcrumbs along a path being walked by a user. These breadcrumbs are then consolidated into a series of waypoints using the Ramer-Douglas-Peucker algorithm [3]. When a user seeks to navigate back along the route, Clew provides guidance from one waypoint to the next through a combination of haptic, spoken, and auditory feedback.

Methods and Implementation

User Interviews

Throughout the process of developing Clew Maps, we worked with a group of 24 codesigners from the BVI community familiar with a range of O&M skills. These codesigners had a diversity of visual impairments and experience with Clew. We worked with these codesigners in one-on-one interviews, small focus/interest groups, and asynchronous communication over Slack. Throughout the process, codesigners also provided continual feedback on both Clew and Clew Maps through beta testing in the Testflight app.

User Experience

In Clew, any given user takes on both the role of a route recorder and a route navigator. A route recorder sets a route by walking along a path and setting anchor points at the beginning and end of a route. A route navigator aligns to these anchor points and is guided along a pre-recorded path by the Clew app. In Clew, users have the option to export a recorded route as a custom .crd file. This functionality is limited to direct device-to-device communication and hidden under multiple screens within the app (see Figure 2), making it presently an underutilized feature by Clew's user base. Clew Maps introduces a cloud database that stores routes, allowing for both crowdsourcing of route data and larger scale distribution of any given route. A data storage schema was designed to streamline the experience of sharing routes, while still providing enough comprehensible information to the route navigator after downloading a shared route.

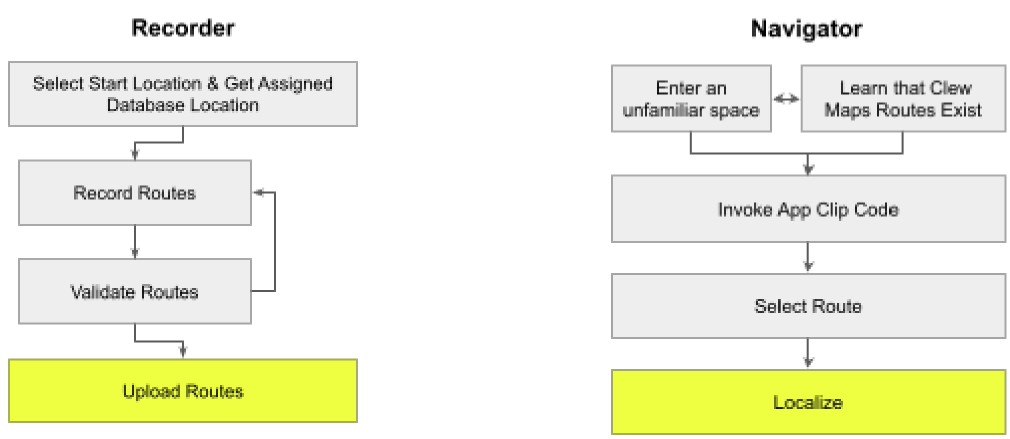

Figure 1. *A flowchart of events from the recorder and navigator side of Clew Maps. While there is much similarity in how these roles function compared to Clew, they differ in the introduction of uploading for recorders and the initial discovery phase for navigators.*

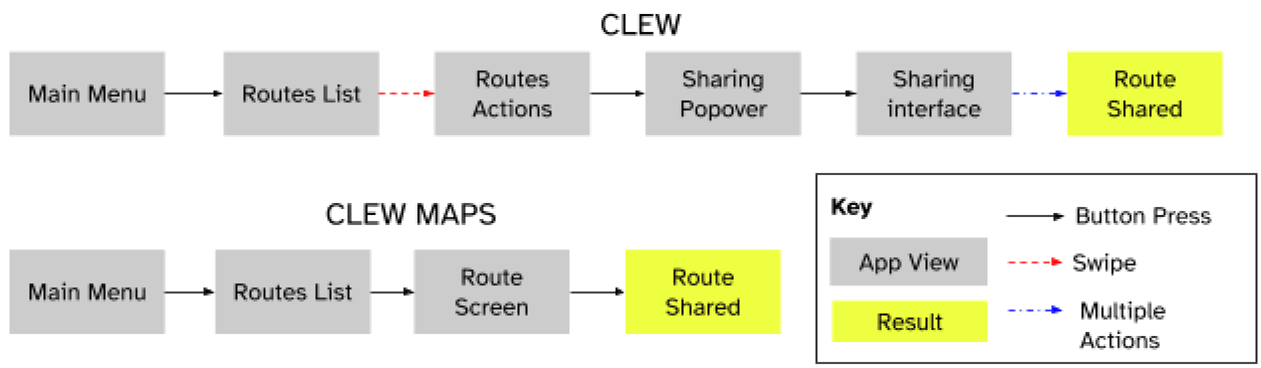

Figure 2. App Interface Flow Diagrams for Route Sharing *These flow diagrams highlight the key views that a user must interact with in order to share a roupe in both Clew and Clew Maps. Notably, Clew Maps limits the number of interactions, and removes all non-button-press interactions, such as swipes which can be unintuitive to discover with VoiceOver.*

Image Anchoring

All location and orientation data in an ARKit Augmented Reality (AR) session is relative to the basis of the session, which is set in the pose of the device when the session is initialized. Since it cannot be guaranteed that users will start recording and navigation AR sessions with their device in the exact same pose, there is a need for a transformation from the navigation space basis to the route space basis (Equation 1). As demonstrated in Equation 2, this transformation can be found using the transformation from each of these bases to a known, fixed location in physical space.

$$B_R = {}^{R}_{N}T * B_N$$

Equation 1: *Change of basis (B) from navigation space (subscript N) to recording space (subscript R). As ARKit poses are recorded in 3D space, the transform matrix (T) is of size 4x4*

$${}^{R}_{A}T * ({}^{N}_{A}T)^{-1} = {}^{R}_{N}T$$

Equation 2: *Derivation of the transformation matrix T referenced in Equation 1, by multiplying transformation matrices from the anchor location (subscript A), to recording (subscript R) and navigating (subscript N) spaces. These transformation matrices are returned by ARKit when an image anchor is detected.*

In Clew, this is the phone position during anchor point alignment, under the assumption that the user is holding the phone in the same position every time. Interviews with O&M instructors and BVI individuals revealed that the original process of setting and finding a Clew anchor point is a skill that takes time to hone and varies considerably from person to person. In order to remember where an anchor point was set, it is important to choose a location that is distinct. Distinctiveness is dependent on a number of factors, including level of sight, experience with Clew, and personal use cases for Clew. Because of the asynchronous nature of

Figure 3. *The image used as an image anchor. This image of an oak tree was selected because organic visuals are highly recognizable by ARKit in comparison to QR codes or other pixelated images*

route sharing with Clew Maps, in which a navigator will likely not have direct communication with the recorder, we believe that the transition to an anchor location external to the phone will aid in establishing consistency in routes navigated with Clew Maps.

Clew Maps leverages the Swift class ARImageAnchor, which can be detected throughout an AR Session. Each ARImageAnchor has a reference image associated with it, and when an ARImageAnchor is detected in the frame, it returns a transform matrix to indicate its position in physical space. This ARImageAnchor transform is stored in the Clew Maps route data as a user navigates the route, and utilized in Equation 2 to transform the navigation basis onto the recording basis.

Data Storage

Route data is stored in a Firebase database which consists of two primary file types. The first is an identifiers .json file, which stores a dictionary of route IDs (unique to each route) and route names (presented to the user) for each 3 digit code associated with a specific App Clip Experience. The second is a navigation file, a custom .crd file that stores route data such as waypoints and the route ID. Any given navigation file can be associated with its identifier file with the route ID. In this system, the small identifiers file is downloaded when an app clip experience is invoked until the user selects a route, at which point only that route data needs to be downloaded, as opposed to every route associated with that app clip experience.

Results and Discussion

Key Values

Exploratory interviews highlighted values held strongly in our codesign group, which informed the design process of Clew Maps. A brief summary of the most broadly held beliefs is given below.

Independence: Independence was the most commonly recurring individual value in exploratory interviews. If an unfamiliar space is inaccessible, many people who are BVI have no choice but to travel with a sighted companion.

Context: Many codesigners mentioned contextual information provided by sighted guides, such as the location of obstacles and the rationale for moving off of a path, as useful information that Clew could potentially provide. More immediately implementable context includes incorporating clock-face/degrees for turns and more obvious distance information (i.e. “Continue straight for 15 feet, before turning left to 10 o’clock”).

Planning: Especially in the context of App Clips, codesigners felt it was important to provide some information ahead of time for existing Clew users to discover that Clew Maps routes exist in a space that they are hoping to travel to. Codesigners expressed interest in GPS-based notification systems that would inform users of routes in their area and provide rudimentary guidance to the starting point. Generally, there was concern regarding the discovery of app clip codes, which are a primarily visual medium, may not be feasible for BVI individuals.

Functionality

User Interface

In addition to virtual codesign, the image-based anchoring system was tested by one in-person user. Initially, the user was informed that the image anchor was "located on the table" he was standing in front of, and the user was unable to correctly scan the image anchor and was directed to feel for the image on the table, after which he was able to successfully anchor and begin navigation. This user also tested anchoring from a vertical image mounted to a flat wall, and to a horizontal image linked to an audio beacon. He was able to locate and scan both of these image anchors more quickly than the initial image anchor, however more testing is required to accurately assess the reliability of these image anchors for in-person, asynchronous route navigation.

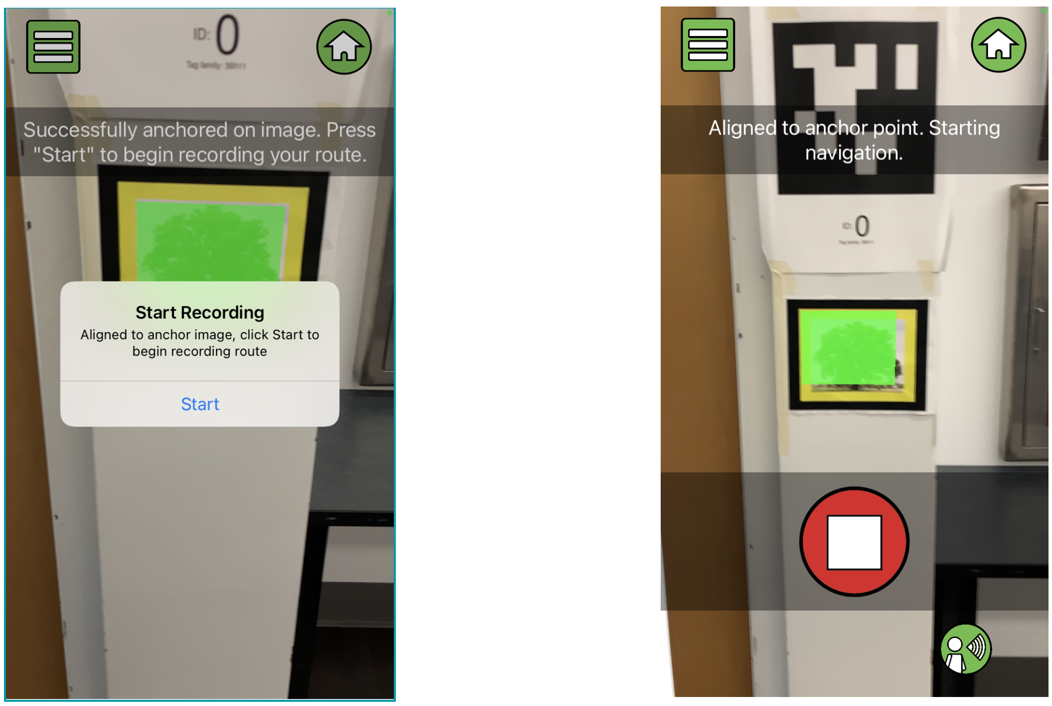

Figure 4. *Screenshots from the Clew Maps anchoring process. (Left) A correctly aligned anchor point in route recording mode. After the anchor point is found, the user must respond to an alert to indicate that they are ready to begin recording. (Right) A correctly aligned anchor point in route navigation mode. Navigation begins immediately after the image is detected, and the alert from the recording mode does not appear to minimize the number of steps a user must take to navigate a route*

Conclusion & Further Work

Currently, Clew Maps is a functional standalone app that expands on the indoor navigation capabilities of Clew to enable route sharing and anchor point alignment, utilizing a newly developed cloud database schema and an application of Apple's ARKit ARImageAnchor detection capabilities. A strength of Clew Maps is that it has robust support for many types of discovery and application. The discovery process for loading a Clew Maps route is open ended - a user can choose to load either from an NFC tag or by entering a 3 digit code. External to Clew Maps, Apple Developer users can configure App Clip settings to invoke Clew Maps from an App Clip Code, a visual code released by Apple. The introduction of Image Anchoring also enables Clew Maps users to anchor off of an image placed on virtually any planar surface. Clew Maps is limited by a lack of understanding of how easily BVI users can anchor using the ARImageAnchors and how discoverable app clip codes are in a public setting. In order to better understand both of these variables, future work should include implementing a real-world study of Clew Maps in a public space such as a grocery store, pharmacy, or hospital.

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