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16. Abstract

PedPal is a smartphone app designed to assist pedestrians with disabilities in safely crossing signalized intersections through real time interaction with the SURTRAC ATSC system running at the intersection. Motivated by the desire to provide a cheaper and more broadly deployable variant of PedPal, this report describes the design of PedPal Lite, which eliminates the App’s dependence on SURTRAC and instead interacts directly with any NEMA-compliant controller running at the intersection. Other App improvements relating to the use of ultra-wide band beacons at the intersection to improve App localization capabilities and the capability to detect user movement outside of the crosswalk during crossing are also described.

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PedPal Lite: An ATSC-Independent Safe Intersection

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FINAL REPORT

October 30, 2024

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1.0 Overview

PedPal is a smartphone app designed to assist pedestrians with disabilities in safely crossing signalized intersections, developed originally as part of the Federal Highway Administration's Accessible Transportation Technology Research Initiative (ATTRI) [1,2]. PedPal interacts directly with the SURTRAC adaptive traffic signal control (ATSC) system [3,4,5] operating at the intersection using real-time traveler-to-infrastructure (T2I) communication and standard DSRC messaging to provide crossing support to its user. Upon arrival at a given corner of a signalized intersection, PedPal receives and presents information to its user about the intersection's geometry, crossing options, and current traffic signal state. When the user indicates her crossing intent, the app then communicates this information to the intersection (eliminating the need to locate and push a pedestrian call button), along with how much time is required by the user to safely cross the intersection. In response to receiving this information, the traffic signal system will set the pedestrian crossing time in the desired direction to ensure that upon getting the crossing signal, the user will receive the crossing time that has been requested. As the user crosses the street PedPal monitors the user's crossing progress in real-time, to recognize when the user is traveling slower than expected, and to trigger the traffic control system to dynamically extend the crossing time in such circumstances. The PedPal app is integrated with the smartphone's native accessible features and provides visual, auditory, and haptic interaction modalities.

The goal of this project has been to produce a cheaper and more broadly deployable version of PedPal. Whereas the ability to exploit surtrac's real-time ATSC capabilities does enable some advanced capabilities such as dynamic extension of the current phase duration that enhance safety, the deployment cost of adopting SURTRAC to municipalities presents a potential barrier to widespread deployment of the PedPal technology. Furthermore, a subsequently funded Mobility21 UTC project [6], which focused on broader technology support for the `complete trip', has expanded the scope of PedPal's capabilities in several new safety-related directions, none of which depends on interaction with SURTRAC. Given these motives, the target of this project has been the design and development of a cheaper and more deployable version of PedPal that is decoupled from the surtrac ATSC and instead interacts directly with the controller that is running at the intersection.

Toward this end goal of enabling widespread deployment of the PedPal technology, this project has produced the following technical accomplishments:

- An expanded PedPal cloud server has been designed that includes an option for PedPal to exchange messages directly with the hardware controller in the cabinet, instead of sending and receiving messages from the surtrac system that runs locally at the intersection in a surtrac deployment. When run in this non-surtrac mode, the cloud server utilizes a local Wi-Fi or cellular connection to either a V2I-Hub module running on a local processor in the cabinet or (in the case of some more advanced controllers) a separate proprietary device that carries out the same function as V2I-Hub. In both cases, NTCIP controller protocols are assumed.

- A scheme was developed for effectively establishing connectivity with Ultra-Wide Band (UWB) beacons positioned at each corner of the intersection. This scheme eliminates the need to rely on Bluetooth, which proved unworkable in our initial experimentation with UWB beacons and forced us to use UWB-equipped iPhone minis with a cellular connection to the cloud to initially demonstrate corner detection and progress tracking capabilities.
- Finally, building on these two UWB-enabled capabilities, the ability to detect or predict movement outside of the crosswalk during a user crossing and haptically signal corrective action to the user was developed and demonstrated in simulation.

In the subsections that follow, we describe these accomplishments in more detail and summarize next steps, including plans to deploy the app for extended pilot testing in the field in 2025. We begin by briefly reviewing the PedPal smartphone App, to provide background and context.

2.0 Background

The PedPal smartphone app for safe intersection crossing interacts with the traffic signal system operating at the intersection in real-time to (1) obtain information about the geometry of the intersection and its current signal timing plan, and (2) to communicate requests for adjustments to the current timing plan based on user specific attributes (e.g., crossing speed). The version of the PedPal app originally developed within the FHWA ATTRI program [1,2] was designed specifically to exploit two core technologies:

- the SURTRAC real-time ATSC system [3,4,5] and the flexibility it provides to dynamically extend crossing times, and
- Connected vehicle technology such as Dedicated Short-Range Communication (DSRC) Radios and emerging DSRC messaging standards to enable real-time connectivity between the smartphone App and the traffic signal system.

Over the course of this two-year project, two distinct PedPal system architectures were explored, depicted below in Figure 1. During the first year, an attempt was made to build directly on DSRC technology. An initial version of PedPal App was implemented on the iPhone and the iPhone was coupled with a DSRC sleeve (made by Arada Systems) to enable real-time communication with a DSRC Roadside Unit (RSU) mounted at the intersection, The iPhone used Bluetooth to communicate with the Sleeve and the sleeve used DSRC to communicate with the RSU. The RSU then interacted directly with the Surtrac Processor running in the traffic cabinet. As usual, Surtrac monitored vehicle traffic in real time through video cameras mounted at the intersection and issued commands to the hardware controller whenever it determined it was time to move to another phase. The SURTRAC services module was augmented to utilize V-I Hub software both to generate and send relevant outgoing DSRC messages and to receive and interpret incoming DSRC messages. Four standard DSRC message types were implemented:

- A MAP Message – that was broadcast to the PedPal app and received as the user approached the intersection, providing information about the geometry of the intersection (number of lanes, names of streets, locations of crosswalks, etc.)
- A Signal Phase and Timing (SPaT) Message – indicating the current SURTRAC projection of when different phases will next become active and for how long
- A Signal Request Message (SRM) – for communicating a request to extend the length of a crossing phase to accommodate the PedPal user's crossing speed
- A Signal Status Message (SSM) – for confirming to PedPal whether a SRM to extend a phase was granted or denied (for example due to violation of the max crossing time constraint)

Reliance on this DSRC message set has persisted and continues to enable the interaction sequence with the PedPal user shown through PedPal's visual interface in Figure 2 but also accessible via voice over for vision-impaired individuals.

While this system architecture was shown to work in the field, it proved to be unreliable, and in preliminary user testing at the end of year 1, the clunkiness of the sleeve/phone app was difficult for users to overcome. This gave rise to a second system architecture in year 2 (also depicted in Figure 1) that replaced reliance on DSRC technology with cellphone connectivity to a cloud server responsible for relaying the same set of DSRC messages between the intersection via a WIFI connection to the SURTRAC traffic signal network and the PedPal App. A user field test conducted with members of the local disability community at the end of year 2 found overwhelmingly positive support for the PedPal app running in this new system architecture, particularly with vision-impaired and mobility challenged individuals. For more details of this user study, please see [8].

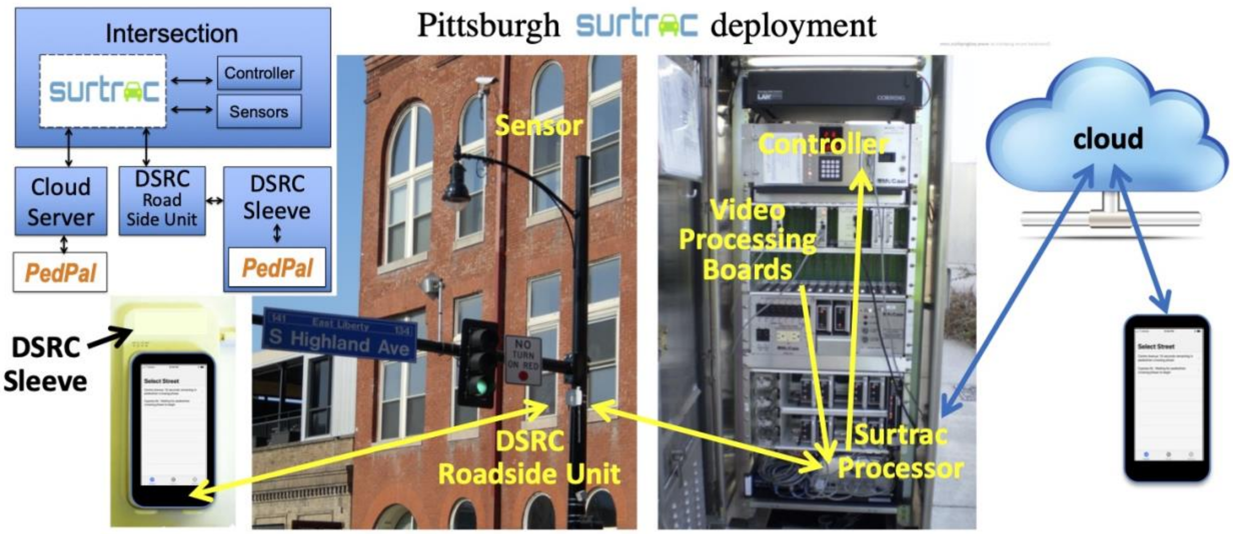


Figure 1: Original PedPal System Architecture

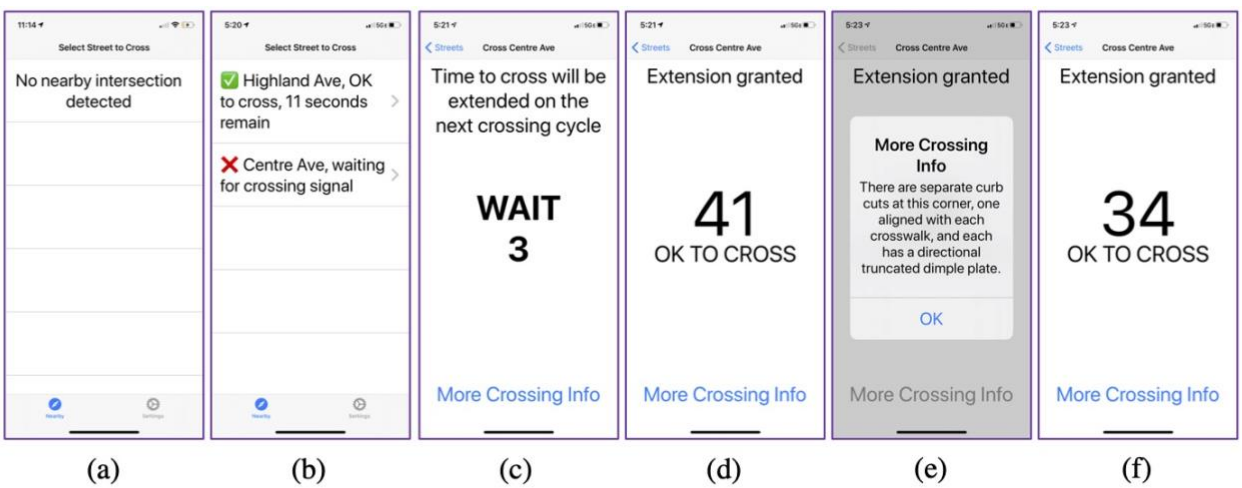
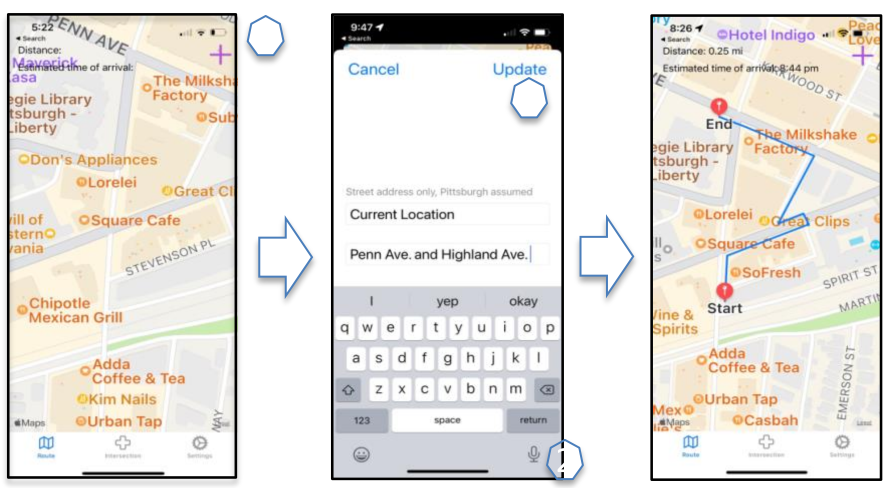


Figure 2: Basic PedPal support for crossing an intersection. (a) out of range from the intersection; (b) MAP and SPaT message received and crossing directions presented to the user, when user selects crossing direction and SRM is sent to the traffic signal system; (c) SSM is received that indicates phase extension has been granted, since crossing phase is not yet active, the App instructs user to wait; (d) Crossing phase becomes active and the app informs the user is it OK to cross; (e) user can ask PedPal for any additional information it has about the corner crossing; (f) the app begins to countdown the phase as the user crosses.

One deficiency of the cloud server-based system architecture coming out of Year 2 of the ATTRI project was the inability to accurately detect proximity to intersection corners with native iPhone localization capabilities. In fact, to achieve the desired user experience in the just mentioned user field test, some amount of "Wizard of Oz" experimental assumptions had to be introduced. Specifically, automatic recognition of intersection corners by the app upon arrival was simulated by manually sending a signal to the app at the appropriate time, to overcome the inaccuracy of the smartphone's localization capability. A subsequent Mobility21 UTC project [8] focused on addressing this shortcoming through introduction of additional infrastructure sensing capabilities. The use of Bluetooth beacons, pre-positioned at each corner of the intersection was first explored, was first explored but found to be rather unreliable as a means of improving localization. However, the emergence of Ultra-Wide Band (UWB) communication (e.g., as found in Apple's air tags) was subsequently found to yield localization accuracy on the order of a couple centimeters, providing a clear path to a solution to the corner detection problem as well as user progress tracking and realization of some new capabilities such as detection of pedestrian movement outside of the crosswalk. Subsequent work here has used Apple's Nearby Interaction framework to enable communication between UWB beacons situated on light poles at each intersection corner and the PedPal app and to achieve accurate corner detection as well as the ability to reliably track user progress during crossing. Initial algorithms for pedestrian trajectory prediction and detection of movement outside of the crosswalk have also been developed and tested preliminarily in simulation. [9]



(a) (b) (c)

Figure 3: Requesting an Accessible Route: (1) Select "+" from initial route view screen to trigger text dialog screen, (2) select microphone to dictate destination location, (3) select update to trigger route generator and display the result.

In 2021-22, work under another Mobility21 UTC funded project sought to broaden the PedPal safe intersection crossing app to provide additional functionality for the `complete trip' [6]. Specifically, PedPal was integrated with an accessible routing service provided by pathVu [10], a local Pittsburgh company focused on sidewalk mapping and accessible routing for wheelchair users. Whereas a routing service like Google Maps or Waze generates the fastest routes for a given circumstance, pathVu's routing app generates a route that is most accessible and safest (e.g., avoiding routes with no sidewalks or sidewalks under repair or avoiding dangerous intersections to cross. In the context of PedPal+ (the name we gave to prototype integrated app), the App toggles between wayfinding and intersection crossing as the user approaches and subsequently departs a given intersection along the route. Figure 3 shows the interface for requesting a route at the outset of a trip.

The integrated PedPal+ prototype, operating with UWB-based corner detection, was successfully demonstrated at the conclusion of the `complete trip' project in the fall of 2022 and subsequently captured on video [11], leading to the current PedPal system architecture shown in Figure 4. This system architecture provides the starting point for the PedPal Lite project summarized in this report.

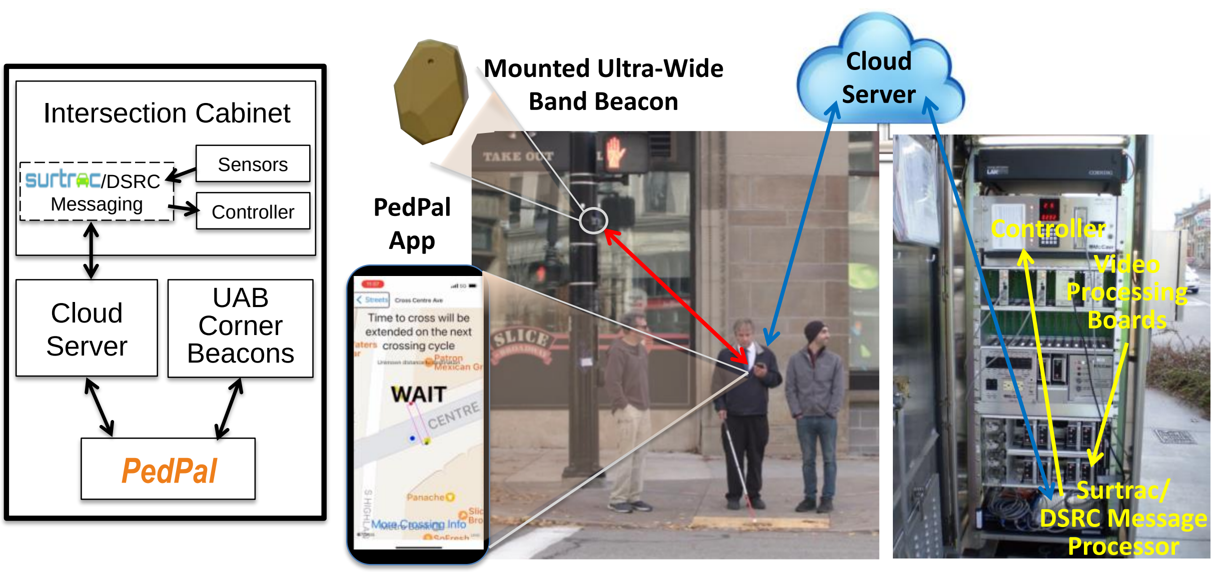


Figure 4: Current PedPal System Architecture

3.0 PedPal Lite

The PedPal Lite project has produced 3 major outcomes. First, it has produced a design for a cloud server architecture design that decouples PedPal from the SURTRAC ATSC system and instead interacts directly with any NEMA controller. Second, a solution is developed to overcome a challenge with Apple's Nearby Interaction framework for establishing connectivity with UWB beacons at intersection corners. Third we implement a new PedPal App capability for detecting and reacting to user movement outside of the crosswalk during crossing. We describe each of these accomplishments in the subsections below.

3.1 PedPal Lite Cloud Server Architecture Design

The PedPal system architecture depicted in Figure 4 anticipates a version of PedPal that does not require the SURTRAC ATSC system operating at the intersection. In this configuration, we assume that there is still local processing power in the cabinet at the intersection, which could be realized by either a separate processor in the cabinet (implied by the Figure 4 architecture diagram) or by a separate DSRC message generation and processing device that is provided by the controller manufacturer. By default, the architecture design specified below assumes that there is a separate processor in the cabinet.

3.1.1 Communication Architecture Design

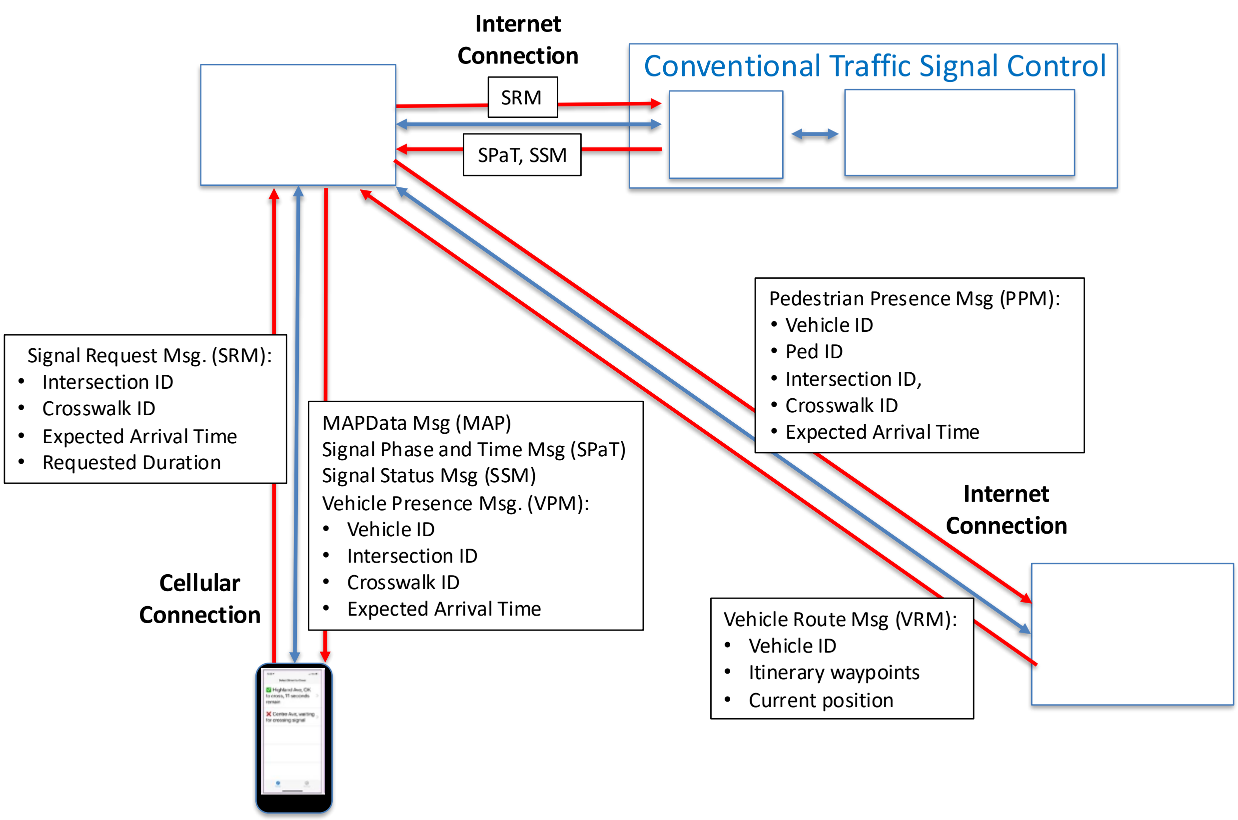


Figure 5: PedPal Lite Communication Architecture.

The PedPal Lite communication architecture mirrors the architecture used by the current PedPal App to communicate with the SURTRAC ATSC system. In this case, the PedPal cloud server acts as a message router, both from the PedPal App to the SURTRAC system running locally at the intersection cabinet and from the SURTRAC system back to the set of PedPal App instances currently moving through the intersection. It maintains a record of the set of active PedPal app instances (users) at different intersections in the network along with their current messaging status (e.g., waiting for a response to a previously sent message, etc.). The SURTRAC services module utilizes a connected vehicle software platform called V2I Hub [12] to formulate and send MAP and SPaT messages to the PedPal cloud server, and to interpret and respond to SRM messages sent from PedPal App instances to the intersection.

Figure 5 depicts the PedPal Lite communication architecture design. The PedPal cloud server can be directly adapted and performs the same message routing and bookkeeping function as before. However, the processor in the intersection cabinet will now run V2I Hub and interact directly with the controller to extract SPaT information for broadcast to active PedPal instances at the intersection and to adjust pedestrian walk times in response to received SRM messages. To maximize coverage, our initial implementation will target interaction with NEMA compliant controllers, which utilize standard NTCIP protocols. We have recently engaged with the City of Pittsburgh's Department of Mobility and Infrastructure (DOMI) to configure an intersection close to campus with a NEMA controller to enable us to field test an initial implementation of the PedPal Lite system architecture. Unfortunately, the vast majority of signalized intersections in Pittsburgh are standardized on older, non-NEMA compliant controllers.

3.1.2 Cybersecurity Issues

Another important communication architecture design issue cybersecurity. The PedPal Lite App utilizes two forms of wireless communication at the intersection: (1) the app receives distance information from ultra-wide band (UWB) beacons mounted at known locations (typically near each corner of the intersection) to accurately track the user's movement through the intersection, and (2) the app interacts through the phone's cellular network with the PedPal cloud server which in turn communicates with the V2I Hub processor and controller at the intersection through the traffic control network's private local area network. Both of these communication channels raise potential security concerns.

The main security issue in the case of UWB communication is that of UWB beacon spoofing, which could result in communication of misleading distance information. This possibility is prevented in the current PedPal app through use of Apple's Nearby Interaction (NI) protocol, which incorporates public/private key cryptography to achieve secure authentication of UWB beacons. Moving forward, we intend to work with UWB beacon venders to ensure that a comparable communication protocol that operates on both iPhone and Android platforms is provided.

For communication between the app and the intersection controller there are multiple issues. For fuzzing attacks that attempt to crash the cloud server by sending repeated malformed messages and overflowing message processing buffers in the cloud server, a <message-length payload> format will be used together with encoding/decoding of standardized Dedicated Short-Range Communication (DSRC) messages to reliably recognize and throw out malformed messages. To ensure a secure failure mode of either the PedPal server or hardware controller (e.g., in the case of a power outage), the App will be programmed to detect if the cloud server becomes unavailable and to notify the user that the app is non-functional until the service resumes. The current PedPal cloud server does not provide any inherent protection against larger denial of service attacks and depends on the safeguards provided by the cloud infrastructure provider. Our thinking is that once we reach the deployment stage, we will work with the cloud infrastructure provider more closely to identify suspicious IP addresses that are flooding the server.

3.2 Establishing App Connectivity with UWB beacons

A second contribution of the project has addressed an outstanding problem in the use of Apple's Nearby Interaction framework to enable communication between PedPal and the UWB beacons pre-positioned at the intersection. In previously demonstrating this capability (e.g., see [11]), one important shortcut was taken. Given the power demands of UWB communication, the Nearby Interaction protocol relies on the UWB beacon's Bluetooth communication to first generate a unique token that establishes connectivity to PedPal. However, as was the case with our early experiences trying to use Bluetooth beacons, this protocol proved to be unreliable. To demonstrate the effectiveness of UWB beacons to achieve accurate corner detection and tracking of crossing progress, we actually used iPhone mini smartphones as UWB beacons at the intersection, which enabled us to generate the initial token in the cloud (using the mini's cellular communication capability).

We have worked with Estimote, a worldwide provider of UWB beacon technology, to find a way to overcome this problem. As an initial solution, we have developed a way to pre-associate tokens with the beacon at the outset and avoid the need for establishing Bluetooth connectivity in the first place. However, Estimote's recently introduced programmable UWB tag technology (see www.estimote.com) appears to offer an even better long-term UWB beacon solution, as it comes with an embedded modem that would support the cloud-based generation of tokens that was utilized in our demonstration. These UWB tags also operate with a re-chargeable battery and USB-C charging wire, which will be essential for eventual permanent deployment.

3.3 Detecting Movement outside of the Crosswalk

A final accomplishment of the PedPal Lite project, building on the localization accuracy provided by the introduction of UWB beacons, has been to implement the capability in PedPal to detect PedPal user movement outside of the crosswalk and subsequently alert the user. Utilizing the trajectory prediction algorithm developed in [9] as a starting point, two detection conditions were implemented. The first simply monitors the user's crossing progress and detects if the user physically moves outside of the crosswalk, using the crosswalk location data provided in the intersection's MAP message. The second detection condition utilizes the above trajectory prediction algorithm to anticipate movement outside of the crosswalk before it happens. If either detection condition is observed, the PedPal app issues a simple haptic alert (one vibration if movement outside the crosswalk is to the left, two vibrations if movement outside is to the right) to enable appropriate corrective action to be taken. This general capability was successfully demonstrated in the lab using an intersection simulator and two iPhone Mini smartphones as surrogate corner beacons.

4. Next Steps

The PedPal Lite project has made good progress toward the realization of a cheaper and more easily deployable version of PedPal. It has also led to the development and submission of a proposal by Sacramento County CA to the US DOT Advanced Transportation Technologies and Innovative Mobility Deployment (ATTAIN) program in February 2024. This project proposal, titled *Sacramento County Complete Pedestrian Trips*, provides the logical next steps for continuing the work summarized here. It proposes a 1-year effort to develop a smartphone mobility app that integrates PedPal safe intersection crossing capabilities and pathVu's pedestrian wayfinding app, essentially a fully hardened version of the PedPal+ prototype developed and demonstrated in [6], followed by infrastructure installation and a 2 year pilot deployment The proposed deployment area encompasses 31 signalized intersections, and much of the included area is federally recognized as a disadvantaged community, characterized by a significant elderly population. In certain areas, the prevalence of disabilities among the elderly reaches rates as high as 60%.

The 2023-2024 ATTAIN awards were recently announced by DOT, and Sacramento County's proposal has in fact been selected for funding. We are excited about this opportunity to fully implement and conduct an extended pilot test our PedPal Lite technology.

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