LuzDeploy: A Collective Action System for Installing Beacons to Enable Accessibility Indoors for Blind People

Submission #4656

ABSTRACT

A long-standing challenge in accessibility has been providing people with visual impairments equal access to indoor spaces. Without access to visual information, it can be difficult to know what is around, where items of interest are, and how to travel to where you want to go. Many solutions for indoor accessibility rely on accurate localization. The most accurate localization approaches rely on augmenting the environment with Bluetooth beacons; however, beacon installation requires expertise. To solve this problem, we introduce LuzDeploy: an end-to-end system that coordinates the installation of beacons by non-expert volunteers who want to help via a Facebook chatbot. We report on a field deployment of LuzDeploy where 89 novice volunteers were orchestrated to instrument a 7-story building. The volunteers performed 99 physical crowdsourcing tasks. LuzDeploy organizes large crowds to perform physical crowdsourcing tasks, solving a long-standing accessibility problem in a way that may generalize to other problems that require altering physical infrastructure.

ACM Classification Keywords

H.5.2 Information interfaces and presentation: User Interfaces - *Input devices and strategies*; K.4.2 Computers and Society: Social Issues - *Assistive technologies*

Author Keywords

Blind users; accessibility; physical crowdsourcing; indoor navigation.

INTRODUCTION

For people with visual impairments, real world accessibility is challenging [14]. Sighted travellers can scan the layout of the surroundings in a long-range with a glance, but blind pedestrians usually can rely only on haptic exploration of their immediate vicinity (*e.g.,* using the white cane). While location-based services can provide outdoor navigation assistance, the dominant approach for indoor navigation consists of augmenting the environment with after-market infrastructure add-ons. For instance, some approaches require the installation of Bluetooth Low Energy (BLE) beacons in the environment to detect a person's current location and inform them of their surroundings [1].

Existing solutions require the navigation infrastructure to be manually installed by administrators with prior training [20]. However, these administrators have limited time [37], so scheduling an installation can be difficult [34]. Training new volunteers to assist in the installation also takes time and effort, and the problem is compounded when a critical mass of volunteers needs to be present at the same time [34, 37].

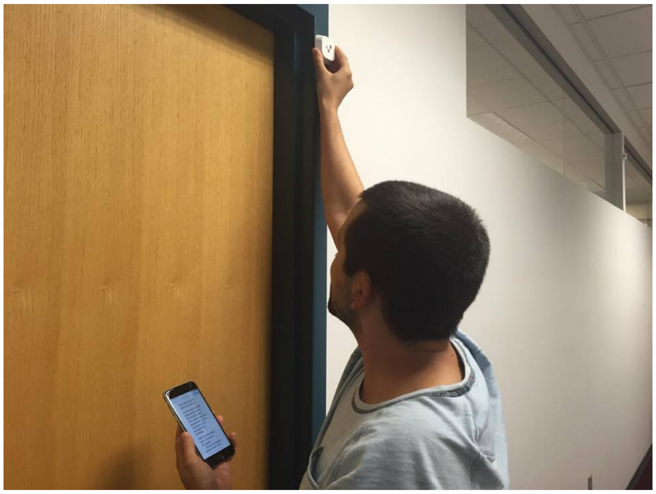

Figure 1. LuzDeploy coordinates novice volunteers to place Bluetooth beacons throughout a building using a Facebook Messenger bot.

We present LuzDeploy: a system that performs live orchestration of a volunteer crowd during instrumentation of an environment for blind indoor accessibility at scale. We designed LuzDeploy to attract a large number of participants with two key features:

1 It allows *anyone to contribute*: LuzDeploy does not require any proprietary software. Instead, it performs the on-boarding and coordination of participants through a Facebook messenger bot, which results in a quick and simple interaction with casual volunteers. LuzDeploy enables even non-experts to participate with minimal training, performed entirely through interaction with the Facebook messenger bot.

2 It enables *anytime volunteering*: LuzDeploy fragments the collective action into a series of simple tasks that can be easily performed even by non-experts in short time. In addition, the system also permits volunteers to join and leave the collective action according to their availability.

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This allows participants with just a few minutes of free time to significantly impact the collective effort.

We publicly launched a collective action with LuzDeploy on a university campus and attracted 89 volunteers to install Bluetooth beacons on 7 floors of a campus building. Our work showcases that it may be possible to engage a broad set of new participants (experts and novices) in physical crowdsourcing. In the following sections, we introduce LuzDeploy in more detail and report on our field study.

RELATED WORK

Crowdsourced Volunteering Systems

Volunteering delivers critical services to communities through collective action, i.e., actions that two or more individuals take to pursue the same collective good. Social computing systems are starting to play an important role in collective action [35]. However, collective action systems are rare because it is difficult to design systems in which a crowd of volunteers can be coordinated to produce large scale change [39]. It is especially difficult to guide crowds to make relevant and useful contributions to the effort [11].

Most volunteering systems focus on making it easy for people to sign-up, input their information, and be matched with relevant tasks [18, 27]. The technological contributions of these systems are primarily matching algorithms that automatically find appropriate tasks for new members based on a measure of their skills and interests [13, 25, 27]. Recently, we have also seen the emergence of research aimed at enhancing volunteer recruitment, by making it easy for people to share volunteer opportunities with friends online [7, 9].

State-of-the-art research has recently started to study mechanisms for orchestrating citizen volunteers during collective actions in order to better produce relevant and useful work [6]. “Games with a purpose” focus on designing game mechanisms that engage crowds to do useful volunteer work while having fun [38, 10]. These systems mainly focus on intelligence tasks that are difficult for computers to complete but are actually relatively easy for humans.

Online micro-volunteering leverages social networks to recruit participants for short tasks [7, 4, 33]. This form of volunteering has recently been used to solve accessibility problems [5]. For example, Brady et al. [7] studied how to leverage existing social networks to answer questions posed by people with visual impairments about the contents of photos. Most work to date concentrates on using online crowd labor to complete intelligence tasks, but LuzDeploy instead applies micro-volunteering to physical accessibility tasks that would otherwise be difficult to automate.

Physical crowdsourcing involves organizing crowds to perform work in the physical world [31, 23, 36]. Heimerl et al. [19] and Goncalves et al. [15] both explored placing physical kiosks throughout universities to motivate passerby to complete expert tasks. While these works show how specific local communities could be engaged on the spot to execute work, LuzDeploy extends the proposed approach by guiding individuals to conduct physical tasks in the area.

Real-world accessibility

Many assistive technologies have been proposed for helping people with visual impairments navigate in unexplored environments. Outdoor navigation assistance commonly relies on GPS positioning [26, 22, 2]. Indoors, however, the GPS signal is often too weak, and even outdoors it is often limited to a localization accuracy of tens of meters [28].

Navigation assistance techniques that do not rely on GPS often involve adding after-market infrastructure to the environment. A popular and widespread approach uses tactile paving [21] on the floor of the environment to signal the presence of paths a blind person can follow with a white cane.

Recent approaches perform localization through sensor-transmitter coupling, with sensor arrays installed in the environment and a transmitter carried by the user [29, 8, 30, 16] or through transmitter arrays in the environment and handheld sensors [3, 32, 24]. In particular, approaches that use Bluetooth low-energy (BLE) beacons [12, 1] have been used to guide visually impaired users with high precision [1].

Transmitter and sensor installations are commonly performed by experts due to the complexity of instrumentation and calibration procedures [1]. However, the cost and time associated with the training of experts can be high, and the amount of work that can be performed by a small number of experts limits the scope of installations to modest environments.

Pebbles [20] proposes to facilitate installation of indoor robot navigation infrastructure by non-experts. We enhance this approach by enabling at scale deployment of blind indoor accessibility through orchestration of crowds of volunteers rather than single individuals. Robot assisted installations, which have also been proposed as an effort to reduce the need for expert human work, have a high cost and the area in which they can perform work is limited [24].

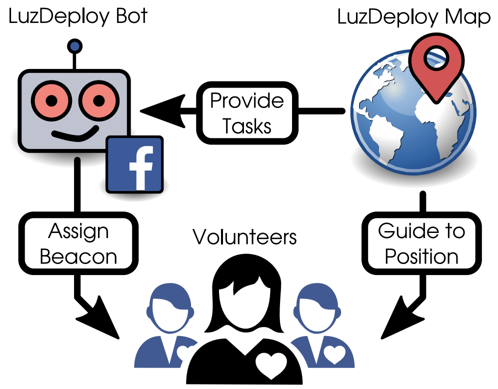
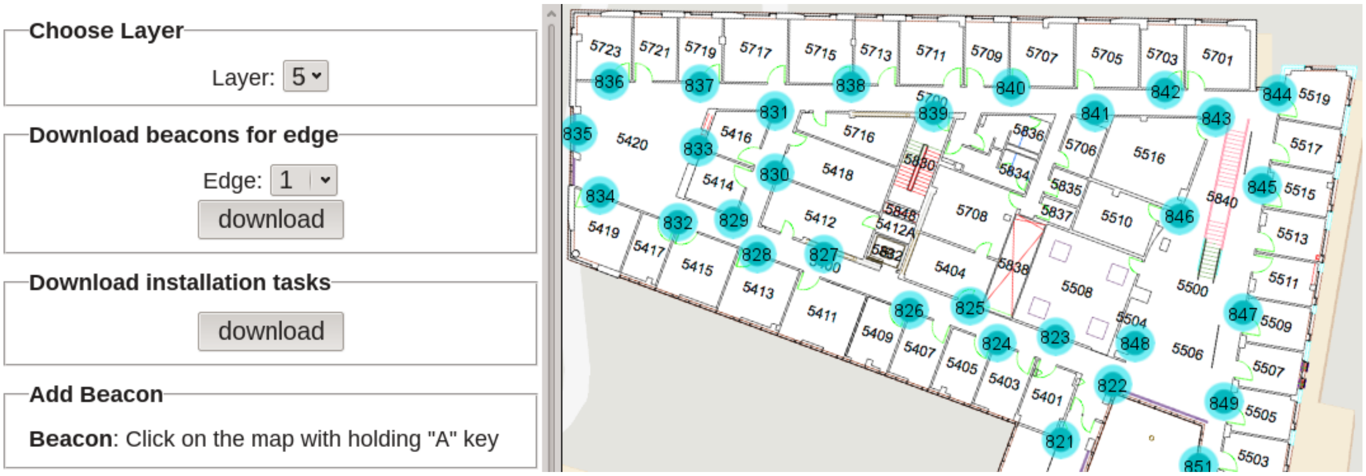


Figure 2. LuzDeploy components: LuzDeploy Map provides the beacon placement tasks, dispatched to volunteers by the LuzDeploy Bot. LuzDeploy Map guides the volunteers to install the assigned beacons.

In this work, we focus on gathering a large volunteer workforce to deploy the navigation infrastructure for NavCog, an open source smartphone navigation assistant that uses BLE beacons for guiding people with visual impairments during autonomous mobility in complex and unfamiliar indoor/outdoor environments.



Choose Layer

Layer: 5

Download beacons for edge

Edge: 1

Download installation tasks

Add Beacon

Beacon: Click on the map with holding "A" key

Figure 3. LuzDeploy Map interface. On the left, it is possible to select layers (floors), download lists of beacons for each path segment or to download all beacon installation tasks at once. The right pane allows to view the floor plan along with the placed beacon markers, or add new markers to the map.

LUZDEPLOY

To provide mobility assistance with a bluetooth beacon-based navigation system such as NavCog, a number of complex and time-critical activities must be performed [1]. Typically, it is necessary to prepare the map data, take measurements of the environment, install the beacons, and collect Bluetooth signal samples across all the areas of the environment. During the execution of the system, it is also required to periodically verify that the beacons are working properly, replace depleted batteries and malfunctioning beacons. While these activities would ordinarily be performed by a small number of experts after prolonged training, our goal is to allow even non-experts to perform the system installation without prior training.

Among the activities required to provide navigation assistance in an environment with NavCog, the beacon placement task is the most numerous as it is performed multiple times for each path segment. As such, it benefits most from a parallelized deployment by a large volunteer workforce. In the following sections we describe **LuzDeploy**, an end-to-end system for efficient orchestration of a large volunteer workforce to install hundreds of beacons. We believe that LuzDeploy can be extended as a future work to address also other tasks related to the environment instrumentation and maintenance.

LuzDeploy has been designed with two core capabilities in mind: 1) *anyone can contribute*: LuzDeploy allows non-experts to significantly contribute during the beacon installation, and 2) *anytime volunteering*: LuzDeploy makes it easy to participate with even only a few minutes of spare time.

The architecture of the LuzDeploy system revolves around 2 core components, shown in Figure 2:

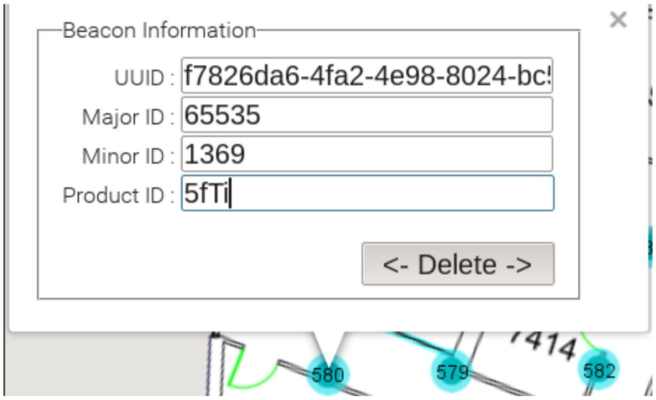
LuzDeploy Map is a remote web service, built over the NavCog map server, that allows administrators to prepare the layout of the beacons in the environment. The positions of beacons, extracted from LuzDeploy Map, are used by the LuzDeploy Bot to create the beacon positioning tasks and to guide the volunteers that have been dispatched to place the beacons to correct positions.

LuzDeploy Bot is a Facebook messenger bot that performs the orchestration logic of the system. Given a list of beacons to position and their coordinates, the bot assigns them to volunteers currently subscribed to the system. The dispatching of the workers is performed on-the-go through chat messages and LuzDeploy Map-based guidance.

LuzDeploy Map

LuzDeploy Map is an extended version of the NavCog map server, built as an overlay tool on top of the Google Maps GIS [17]. It allows administrators to create maps of the environment by adding and positioning the venue floorplans on top of the world map. By holding the *A* key while clicking on the map, an administrator can position markers in the locations where volunteers will be asked to install beacons. Figure 3 shows the administration interface of LuzDeploy Map.

For each marker, in addition to its coordinates, LuzDeploy Map records data used by NavCog for accessing the beacon (UUID, Major ID, Minor ID), and a product ID used by administrators to configure the beacon. These values can be accessed, modified or deleted in the settings window shown in Figure 4, which is opened by clicking on the beacon marker.



Beacon Information

UUID : f7826da6-4fa2-4e98-8024-bc

Major ID : 65535

Minor ID : 1369

Product ID : 5fTi

Figure 4. Beacon information window containing beacon identifiers.

Once the beacons markers are placed, the “Download installation tasks” area allows to download a file containing a list of all the beacon markers in JSON format, including the beacon identifiers and their coordinates. LuzDeploy Bot imports this file to create the beacon placement tasks.

During the execution of the beacon placement tasks, LuzDeploy Bot instructs the volunteers to take a specific beacon from a designated beacon supply station and position it roughly at the location specified on the LuzDeploy Map (see Figure 5).

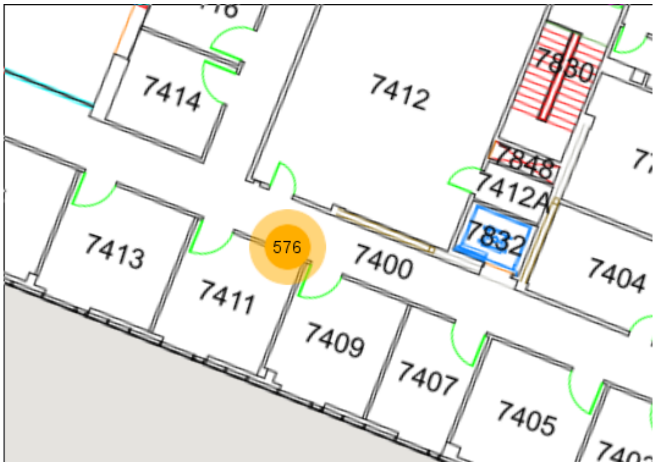


Figure 5. LuzDeploy Map shows the location in which to place a beacon.

LuzDeploy Bot

LuzDeploy communicates with volunteers through the Facebook Messenger Send API[1], which allows sending and receiving both of text and rich interactive messages (*e.g.*, with buttons or pictures). The bot connects this API to a database of task and volunteer information through a NodeJS server. The main responsibility of this server is to handle the onboarding of new volunteers, assign tasks, and track task duration.

The LuzDeploy Bot is capable of defining the composition of the workforce on-the-go by dynamically assigning tasks to the available volunteers. This enables *anytime volunteering*, so that the volunteers can participate towards a collective goal according to their availability. Some volunteers may have to leave the collective action prematurely, while others may join after the deployment has already started.

LuzDeploy also allows *anyone to contribute* by taking advantage of Facebook’s widespread usage among university students, the target volunteer pool for our deployment. This allows volunteers to join the deployment collective action quickly, without downloading any additional smartphone applications. Web browsers also have the ability to provide an interface without downloading a native smartphone application, but a chatbot allows LuzDeploy to notify users of a new task even if the application is not open. The task instructions and information are also contained in a few messages, so it is simple to communicate through a chat interface.

For a volunteer, contacting the LuzDeploy Bot is simple: either type "LuzDeploy" into a Messenger search bar, scan a profile code marker, or visit a short web URL that redirects to the chat application. Once contacted, the bot sends the volunteer condensed instructions on how to place their first beacon, along with a link to LuzDeploy Map that shows the intended location of the beacon. The user is advised to place the beacon on the wall about 3m from the ground and within 1m from the designated position with hook-and-loop stickers.

Command	Action
start	start an assigned task
done	complete a started task
reject	give up a task if you have one
ask	get another task if you do not have one
leave	leave the deployment (can rejoin)
help	request a list of commands or personal help

Table 1. A list of commands volunteers can use with LuzDeploy.

After reading the instructions, the volunteer can use short commands (See Table 1) to start the task when they are ready or reject the task if they are unable to place a beacon at the moment. Once they place the beacon and tell LuzDeploy they are done, the bot will send the next task. Volunteers are free to leave and rejoin the deployment at any time if they do not wish to receive more assigned tasks.

FIELD DEPLOYMENT

We demonstrated the capabilities of LuzDeploy through a beacon installation performed on a university campus. We setup the deployment in a complex, highly-trafficked, 7-story building with the goal of recruiting passerby as volunteers to install beacons.

In order to prepare the building for a navigation application, BLE beacons were numbered and their intended locations were marked on LuzDeploy Map. These locations were manually chosen, based on building floorplans, in order to yield high localization accuracy for navigation assistance with NavCog.

Most of the buildings inhabitants were university students, so we implemented LuzDeploy Bot as a Facebook Messenger chatbot to make it frictionless to begin volunteering. The majority of students already had a Facebook account and Messenger installed on their phones, so they did not need to download an additional application or make an account on another website.

The deployment was executed on a single day from 4PM to 10PM. A stand was placed near a main entrance of the building, where the research team distributed beacons and helped onboard passersby as volunteers. The volunteers were not compensated monetarily but, like many volunteer opportunities, small snacks were provided.

After the end of the deployment, volunteers were asked to fill out a survey about their experience with LuzDeploy that was then distributed via the LuzDeploy Bot.

Deployment Outcome

In total, LuzDeploy attracted 89 participants from passerby during the deployment, with activity peaking around 4PM and

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[1] `https://developers.facebook.com/docs/messenger-platform/send-api-reference`

7PM (see Figure 6), which were times of high foot traffic in the building. We noticed that 13 participants did perform the assigned task but did not remember to start the deployment in the bot chat. These participants and the corresponding 13 beacon placements are therefore not assigned to any of the listed time ranges.

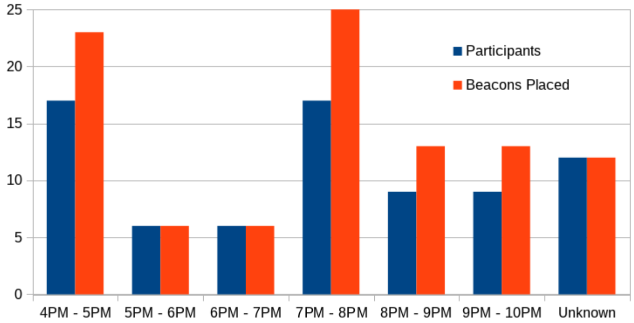

Figure 6. Number of participants and installed beacons per hour throughout the deployment.

During the deployment, a total of 99 beacons were placed. 70 participants, which is 78% of those who signed the consent form, placed at least one beacon, while 11 participants placed more than one beacon (see Figure 7).

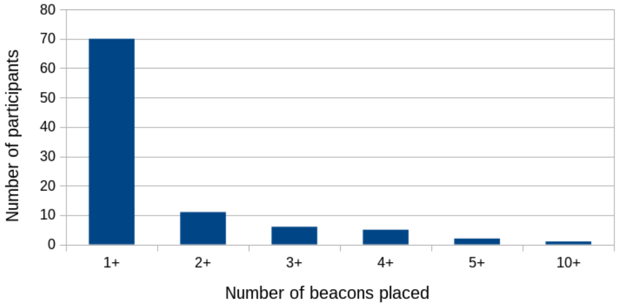

Figure 7. Cumulative distribution of beacons placed per participant.

There were 6 participants who signed the consent form but never joined the collective action to get a task, and 13 participants who joined but did not complete a task. Some of these participants encountered technical issues with LuzDeploy Bot or Facebook Messenger, which is why they were unable to continue with the deployment.

Post-Deployment Survey

LuzDeploy Bot distributed a survey after the deployment to collect volunteers' feedback on the collective action for future improvement. The survey was completed by 21 participants, 23% of those who participated to the collective action. 85% of these respondents reported prior and frequent previous volunteering activities. The most common reason that survey respondents gave for participating in the study was that they thought the project was interesting or fun (8 of 21, corresponding to 38%). Other reasons are reported in Table 2.

Two-thirds of respondents (14 out of 21) found the tasks short and easy. 16 out of 21 respondents (76%) gave input on how LuzDeploy could be improved. The most common improvement for LuzDeploy, suggested by 9 participants (56% of suggestions), was some method of 'batching' to place multiple beacons at once. Volunteers also had various technical and usability issues with LuzDeploy Map they requested we fix in future versions of LuzDeploy.

Reasons to participate	**# of participants**	**%**
Project seemed interesting	8	38%
Participant had free time	4	19%
Invited by a colleague	4	19%
Participant was close by	3	14%
Our stand had food and snacks	3	14%
Interested in accessibility	2	10%

Table 2. Reasons to participate listed by volunteers.

The survey also asked participants to answer why they stopped taking new tasks. Most reported that they had to get back to work or it was late (12 participants, 57%), but some felt they had already contributed enough to the deployment effort and were not motivated to do more (5 participants, 24%). One survey respondent was confused by LuzDeploy Bot's instructions and could not find help.

In order to understand if LuzDeploy could motivate these volunteers to help with additional tasks, we asked if participants would be willing to check on beacons periodically. 11 (52%) wanted to check on beacons provided they had placed them initially, but only 7 (33%) were willing to spend time inspecting beacons placed by others.

Visual Beacon Inspection

One week after the deployment, a visual inspection of each beacon was performed by two members of the research team. NavCog does not need the beacons to be placed exactly at a fixed point, so the beacons were inspected to see if they were within 1 meter of the location marked on the building floor plan. Of the 99 beacons deployed in the building, 73 were on the designated map marker or close enough. During inspection, we found that 6 beacons out of those given to the volunteers were missing and 17 beacons were near the intended location but too far away. Out of these 17, one beacon was found broken apart after the deployment.

We observed some common reasons that resulted in wrong positioning of the beacons:

- **Material matters:** When the beacon was to be placed on glass windows or bulletin boards, many volunteers instead placed the beacons on a nearby wall.
- **Maps are ambiguous:** Beacons that were to be placed in the middle of a bare wall were often off the map marker. This was especially true in hallways where the only distinguishing map features were interior room boundaries not visible to the volunteer.
- **Maps are not always correct:** Some locations on the map could have been landmarks for volunteers, but there was not a corresponding location in the building, as the map was out of date.

- **Height is hard to measure:** We requested that volunteers try to place the beacons about 3m off the ground, but many did not know how high that was. Typically, beacons were placed on door frames and other obvious locations.

- **Orientation is not easy to discern:** Beacons on pillars and wall corners were often not facing the direction intended by the map, as volunteers just tried to get them near to the landmark.

DISCUSSION

Participant Recruitment and Retention

The most exciting demonstration of LuzDeploy during the field deployment was the ability to recruit 89 volunteer passerby in 6 hours. This is in stark contrast with many physical crowdsourcing initiatives (*e.g.*, photomapping events) that usually involve around 10 members.

The number of participants we gathered was highly influenced by the time (mid-weekday) and location (a highly-trafficked building entrance) of the project stand. Many of the building inhabitants who stopped to learn more about the project contacted the bot, and were able to quickly sign up. The short duration of beacon placement tasks was also ideal for recruiting passerby, as many students were travelling between classes or other engagements, and only had a few minutes to devote to the collective deployment effort.

Instead, for the volunteers who had time to complete more tasks, the short duration of each task made the process tedious. LuzDeploy would often ask them to complete a beacon placement task on a different floor before returning to pick up the next beacon. Because of this, most volunteers did not place more than one beacon. To increase participant retention, many volunteers suggested we allow them to pick up multiple beacons to deploy to the same floor or area. In the future we will provide a number of beacons proportional to how much time each volunteer has to spare.

We believe this would have allowed us to deploy far more beacons in a similar amount of time, as it much time was spent finding the correct placement location and travelling there. Members of the research team prototyped this feature by taking a large number of beacons to the same floor with a modified LuzDeploy Map. They were able to deploy 253 beacons relatively quickly with this approach, so a future version of LuzDeploy will include this feature.

There were several other design issues uncovered in LuzDeploy during the deployment. The first was that many participants would forget to tell the bot when they started or stopped a task, making it difficult to accurately estimate task durations. For example, as shown in Figure 6, 13 participants placed beacons without telling LuzDeploy, which caused the bot to get out of sync with the real-world beacon inventory.

Beacon Placement

In the visual inspection of beacons we noticed that even with the LuzDeploy Map, many volunteers struggled to find the exact location to place the beacons, leading to some beacons being as much as 1-2m off from the specific location. This usually happened in areas with few features, such as bare hallways, where it was not easy to describe the correct beacon location. The volunteers also tended to “lock on" to salient locations for beacon placement, such as corners or boundaries on walls. The placement of these beacons likely influenced later volunteers, as many beacons in the same area were placed in a similar way.

Without explicit instructions, volunteers would avoid adhering beacons to surfaces such as windows or walls that were clearly used for another purpose (*e.g.*, message boards). More explicit examples and instructions could also help participants orient beacons correctly on corners and pillars, as well as standardize the placement height. People are generally not accustomed to changing physical infrastructure. In most other cases attaching a physical object to a wall in a building that is not one’s own space might be considered vandalism. Clearly, issues of trust and authority will need to be considered in the development of future systems. Should rogue deployments of beacons in places where permission has not been granted be explicitly discouraged? How will volunteers know the difference?

This realization adds a second constraint to the task of designating the beacon locations for the deployment. Not only do we have to consider the beacon locations that lead to high accuracy for NavCog, but we also have to consider which locations are more suitable from the volunteers’ perspective. Less ambiguous map locations will likely lead to deployments with more accurate beacon placements.

Some areas of the building were restricted to those with key card access, so volunteers who did not have access needed members of the research team or other volunteers to accompany them. Other areas were restricted entirely, so volunteers were unable to place those beacons. LuzDeploy Bot will take access control lists into account in future versions to account for the permission levels of different volunteers to achieve a full deployment.

Long-term Investment

At the moment, LuzDeploy assists a volunteer workforce in the installation of beacon infrastructure, however we believe that the system could be re-purposed for other distributed volunteering tasks, such as data collection. For more difficult tasks, LuzDeploy will need to automatically ensure volunteers maintain a high quality of work.

One of the most valuable areas for LuzDeploy to be applied is in the less-intense maintenance phase of a navigation system. Many survey respondents were willing to complete additional tasks to inspect and repair the beacons, but more were willing to do so for the beacons they had personally placed. This could be a reaction to the perceived volume of beacons, as volunteers only want to maintain the few they placed, not the hundreds others might neglect.

On the other hand, it is possible that volunteers feel some investment to the beacon they personally placed, and are therefore more likely to participate in the upkeep of that portion of the infrastructure. Therefore, LuzDeploy not only needs to raise immediate interest, but also encourage commitment to follow-through. We intend to investigate how personal involvement in the placement of beacons influences volunteer retention during follow-up activities.

CONCLUSION

We have introduced LuzDeploy, a Facebook chatbot that coordinates volunteers to instrument buildings with bluetooth beacons. In our field deployment, passerby volunteers installed bluetooth beacons to enable a navigation assistant to guide people with visual impairments through indoor spaces. These deployment tasks would normally be performed by experts, but were instead successfully completed by a non-expert workforce.

LuzDeploy enables *anyone to contribute* by distributing simple and easy-to-understand tasks to anyone with a smarthpone and a Facebook account. LuzDeploy allows the participants to join and leave the collective action at will, enabling for *anytime volunteering*, as passerby can contribute even in small chunks of spare time. LuzDeploy capitalizes on these two features to deploy accessibility installations at scale, thus solving a long-standing challenge in blind navigation assistance. Future work may look to extend LuzDeploy to other physical instrumentation tasks or to providing on-going maintenance of installed infrastructure.

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