Combining Schematic and Augmented Reality Representations in a Remote Spatial Assistance System

Huaming Rao, Wai-Tat Fu

Abstract—Remote collaborative systems allow people at remote locations to accomplish a task as a team. One unique and critical challenge for these systems is to support communication of spatial information, as people at remote locations cannot anchor their conversation by directly referencing objects in the same spatial environment. We focus on the task of indoor navigation assistance to highlight this challenge, and propose a general framework that allows two or more persons at remote locations to better communicate and make spatial inferences. We show how schematic representations and augmented reality tools can be combined to help them establish anchors that allow them to both see and refer to the same locations, such that the users can develop a richer representation of the spatial environment. The tools can also provide guidance on actions and facilitate spatial inferences. We demonstrate this idea using a version of remote spatial assistance to a local user who navigates in an unfamiliar indoor environment. The system aims at efficiently connecting the local user and the remote expert to collaboratively infer and develop a spatial plan, locate and correct the position of the local user without the use of a GPS system, and provide spatial guidance using landmarks developed by the pair of users. The system demonstrates the combination of an autonomous system and human computation system. Implication to future development of such systems for remote spatial assistance is discussed.

1 Introduction

Recent advances of modern technologies make collaborative work more distributed, in ways that allow one to get assistance not only from nearby but from all over the world. Systems that support remote collaboration should facilitate communication such that the two (or more) persons can work towards the task together by making inferences and solving problems along the way. One unique and critical challenge for these systems is to support communication of spatial information, as people at remote locations cannot anchor their conversation by directly referencing objects in the same spatial environment as they do when they are co-located. The goal of the current paper is to discuss why and how the combination of spatial representations using schematic maps and augmented reality views can help users to better communicate spatial information. We will focus on the task of indoor navigation to illustrate the idea.

When navigating outdoors, mobile map applications, such as Google Map, can do a good job in locating your position using Global Positioning Systems (GPS) on its digital map and provide recommendations on appropriate routes to your destination. The situations is different for indoor navigation. Floor maps are not always available for all buildings and GPS systems are often not as applicable as in outdoor navigation. As a results, sensor signals, such as those from the gyroscope, accelerometer, bluetooth, and WiFi that are available in most mobile devices are being extensively studied to replace GPS systems for indoor navigation. Another alternative is to use the camera to capture pictures of the environment and to utilize computer vision techniques to determine the location. At the time this paper is written, these techniques often either have low accuracy due to fluctuating signals or have slow response times due to hardware limitation and time-consuming computations. Without a proper floor map and accurate positioning methods, it is difficult to pinpoint the location of a person indoors, let alone providing navigation assistance.

Indoor navigation is a difficult task as it is often hard for one who's new to the building to locate himself/herself just by looking around, as there is often a lack of unique environmental cues. People therefore quite often lose their sense of direction when navigating indoors, even with a floor map (e.g., when navigating in a mall). One intuitive solution for indoor navigation assistance is to ask someone nearby for directions. However, when no one is nearby, can one pull out their cell phones and talk to someone at a remote location to seek spatial assistance? Of course, if the remote person is completely clueless of the environment, he or she will not be able to help. But if we assume that the remote person either has some knowledge or experience with the environment (an expert), or someone who has access to a partial floor map of the building, how can the remote person help the local user to navigate?

- *Huaming Rao is with Nanjing University of Sci & Tch and University of Illinois at Urbana-Champaign. E-mail: huamingr@illinois.edu.*
- *Wai-tat Fu is with University of Illinois at Urbana-Champaign. E-mail: wfu@illinois.edu.*

2 Related Work

In general, there are two main streams of indoor positioning technologies: sensor-based and vision-based. Liu et al.' survey[12] provides an overview of the existing wireless indoor positioning including triangulation, scene analysis, and proximity. Besides radio signal sensors, the gyroscope and accelerometer now available in most smart phones today can also be used to locate user's position [15] by detecting when the user takes a footstep using the accelerometer and determining the direction of the footstep using the gyroscope. And thanks to the features that are invariant to changes in illumination, view point, scale, image translation and rotation[13, 5, 18], it is possible to apply computer vision techniques to mobile indoor navigation systems. Besides developing the applications of indoor navigation, some researchers [10, 1, 7] also focus on the evaluation framework of how to combine the key aspects of building indoor navigation systems.

The ideas and concepts of augmented reality(AR) is to improve the depiction of virtual objects over a real scene. The major strengths of this technique is its intuition for presenting information, so it's been widely used in many systems. Mulloni et al.[14] presented a novel design of an augmented reality interface to support indoor navigation which combined activity-based instructions with sparse 3D localization at selected info points in the building. Some researcher[17, 8] provided hybrid indoor/outdoor solutions for spatial guidance using 3D gesture.

A number of researchers[3, 4, 6] have identified unique challenges and solutions in different task scenarios by studying remote collaboration. While those research on developing autonomous systems has made significant progress, significant challenges remain. Rao et al. propose that an optimal mix of computing and human agents that can provide a cost-effective approach for many practical problems. Lasecki et al.[11] recruit Amazon Mechanical Turkers to control a Rovio robot to navigate to its destination. Studies[16] also shows that a spatial location identification task by asking Turkers to identify the location of some pictures on a two-dimensional map can be performed at certain accuracies even if they do not know about the environment.

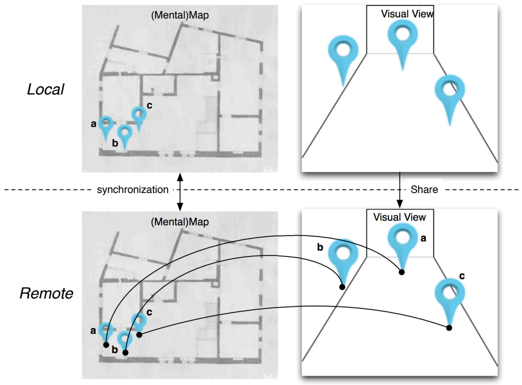


Fig. 1: General Ideas: Remote users either have clearer mental map in mind or have a floor plan of the environment; The remote user obtain the camera view from the local user to identify objects or landmarks in the camera view by associating these objects with spatial cues in the floor plan; The generated spatial plan can be synchronized between both sides

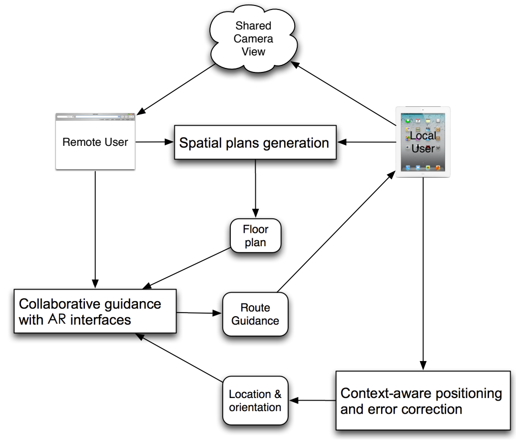


Fig. 2: Framework of the Proposed System: it consists of three components: 1) Context-aware positioning and error correction; 2) Spatial plans generation 3) Collaborative guidance with augmented reality interfaces. These components can be combined to allow the remote user to collaborate with the local user.

So combining existing techniques of indoor positioning, augmented reality, remote collaboration etc., it is promising to build a remote spatial assistance system by effectively connect the local user and a remote user to accomplish the task collaboratively, but the main challenge for designing such a system is how one can more effectively use human computation to complement computing agents and support communication of spatial information. Similar discussion had been covered by Hollerer et al.[9] who developed an indoor and outdoor user interfaces to a mobile augmented reality system that allowed a roaming outdoor user to be monitored and provided with guidance by remote experts.

3 Proposed System

A stranger new to a place has many difficulties to navigate to his/her destination mostly because: 1) he/she dose not yet recognize most of the objects around especially those landmarks which are the key spatial cues for navigation 2) he/she does not yet shape a clear mental map in his mind that illustrates the geometry relationship between the objects in the environment 3) he/she does not yet build the associations between the objects in his/her view and their locations in his/her mental map which help him/her to identify his/her current position. All those factors make it very hard for a stranger to choose the right directions. While an expert who knows the place well (or have a floor plan) might have much more clearer mental map in mind, enough information about the objects around and the capabilities to associate what he/she is looking at onto the point in his mental map. So we design our remote spatial assistance system to fill those missing parts for the local user with the help of a remote user by effectively transferring what the local user is seeing to a remote user who is familiar with the area or can access to the floor map and synchronizing the collaboratively generated spatial plans, such that interactive assistance can be provided to the local user. The general ideas are shown in Fig. 1.

3.1 Overview of the Framework

We adopt the general sensor-based indoor positioning techniques to approximately estimate a user's position. The sensors include WiFi, gyroscope and accelerometer. Based on the local user's position, the remote users work collaboratively with the local user to perform general spatial planning (e.g., sketch out a floor map of the building), identify critical points in the indoor environment, and provide directional guidance with AR interfaces. The system is designed as a mobile-browser application with a server transferring information between local users and remote users and restoring building floor maps. Fig. 2 shows the general framework of the system, which consists of three major components: 1) Spatial plans generation; 2) Context-aware positioning and error correction; 3) Collaborative guidance with augmented reality interfaces.

The server side of the prototype system was implemented on a Mac using Ruby on rails framework, and the mobile side was implemented on an iPad mini. We also used the OpenTok platform on WebRTC toolbox to make it easy to deliver high-quality, low latency video stream between remote and local sides. In addition, the websocket technique was applied to transfer data between browser and mobile device.

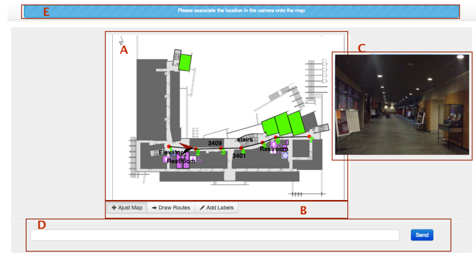
3.2 Interface Design

As said above, the system is designed as a mobile-browser application. The remote side is using the browser to connect an device holding by the local user. Fig. 3 shows the interfaces design of the system.

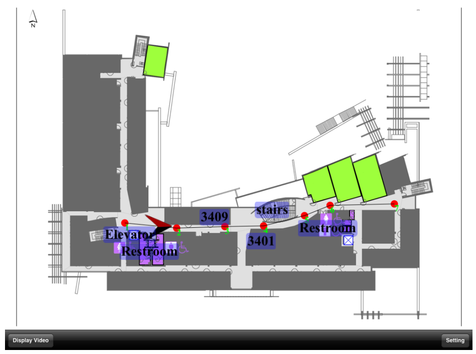
3.2.1 Remote Side

As shown in Fig. 3a, the browser interface for the remote side combines a schematic representation of the environment (in this case, the floor map) and an augmented reality representation from the local user. The schematic representation allows the remote and local users to determine the structural relationships among objects, which help users to make spatial inferences that do not require a realistic representation (e.g., camera view). These abstract representations, however, need to be associated with the realistic views of the local users, such that perceptual operations can be performed by the local users to recognize objects and their spatial relations in the actual environment. The task of associating between semantic and perceptual information is often not straightforward for the local user, especially if s/he is unfamiliar with the environment or pre-occupied with other motor operations. This association task, however, is often important for spatial inferences that are required in task such as indoor navigation. It is therefore more efficient when this task is offloaded to the remote user, with whom the local user is collaborating to perform the spatial tasks.

These two representations can be divided into five components. **A** is the floor map describing the structure of the building. Besides the original floor map, there are also some customize labels as supplement information to enrich the details of the floor map. Moreover, the turn-by-turn route can be drawn onto the floor map to show the directions of how to go from the start point to the destination. The arrow attached to the route indicates the local user's current position and orientation. **B** is the controller bar which provides three main functions: 1) Draw routes: by clicking on the floor map to draw a turn-by-turn route; 2) Add Labels: by clicking on the floor map to put a label to describe that point; 3) Adjust the map: including moving/removing the route points,



(a) Interface for Remote User: **A** is the floor map;**B** is the controller bar; **C** is the shared camera view; **D** is an input area; **E** is the notification center



(b) Interface for Local User with Map View: presented when the device is laid down facing up; the label and the routes are synchronized with the remote side; The arrow indicates user's position and orientation

(c) Interface for Local User with Camera View: presented when the devices is hold up; the virtual signs indicates the estimated position of their corresponding labels or routes on the floor map; 3D arrow is directing at the next route point

Fig. 3: Interface Design

editing/moving/removing labels and moving the arrow to correct local user's current position. **C** is the shared camera view streaming from the device (including audio streaming). This widget is automatically present once the device is hold up (with the interface in Fig. 3c) and hidden once the device is laid down (with the interface in Fig. 3b). As well, it can also be dragged to other place so as not to cover important parts of the interface. **D** is an input area used to send text messages to the local user as guidance or other contents. And **E** is the notification center showing alerts when it comes the requests from the local user. These components allow the remote and local users to associate spatial objects in the environment by combining the schematic and augmented reality representations to facilitate referencing of these objects, and most importantly, they help them to perform spatial inferences that involve the *relations* of these objects in the environment.

3.2.2 Local Side

The interface for the local user is separated into two according to the posture of how the user is holding the device[14]. When the device is laid down facing up, the interface automatically turns to Fig. 3b; When the device is hold up with the camera aiming at the front, it turns to Fig. 3c. Fig. 3b looks similar with the component **A** in Fig. 3a, and actually its elements (labels, routes and arrow) are synchronized with the remote side when the remote user makes changes to the floor map. Fig. 3c is the camera view showing the real scene the local user is facing. It also displays some augmented information that demonstrates the estimated position of the objects corresponding to the labels or route points on the floor map. At the bottom of the interface is a 3D arrow that always directs at the next route point to tell the local user where to go. There is also a notification bar on top of the interface, presenting text messages sent form the remote user.

3.3 Features Description

As shown in Fig. 2, the proposed system is made up of three components, so the rest of this section will give the details of each component.

3.3.1 Context-aware positioning and error correction

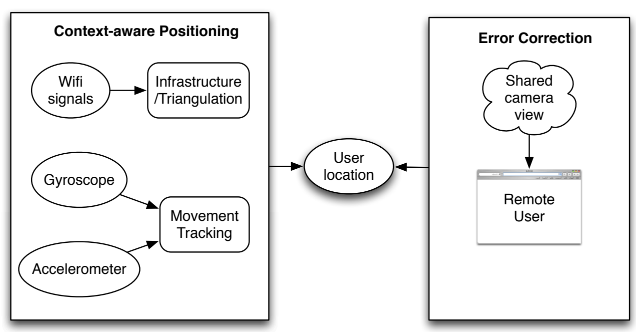


Fig. 4: Workflow of context-aware positioning and error correction: local user's position is first estimated by the autonomous system then corrected by the remote user

Due to the limitations of current indoor positioning techniques, stand-along method may not work well to meet the high requirement of reliability. So the proposed system will use a context-aware way to select the best method to determine user's location. Considering the hardware limitation of the device, vision-based may not be practical for consumer devices, but may become more applicable in the future. Because WLAN is widely deployed in most large buildings. Some network infrastructure may even scan and tell users locations, which means instead of the client doing the work of scanning and calculating, the buildings network will do it. The application just need to ask the network where it is. But sometimes the infrastructure is not supported, then the application should do it itself. So the proposed system will prefer to use WiFi signal and triangulation algorithm to estimate the approximate location of the user. When there is no WiFi signal, the system will drop back to use gyroscope and accelerometer to record user's track and calculate the location [15].

But in practice, the environments are more complex indoor than outdoor due to the walls, the moving people and other electric equipments, which may interfere the signals of electromagnetic waves and the illumination conditions. To overcome these difficulties, the remote user need to be incorporated into the system to manually correct the inaccuracy when the signal is fluctuating (see Fig. 4). As shown in Fig. 6, the local user is automatically located at point **A** with "stairs" in the front and "3409" in the back, but from the camera view on the right, the actual position of the local user should be at point **B** with "Restroom" on its right and both "3409" and "stairs" in the front. This inconsistence between the automatically located position and the scene in the camera view can be easily observed by the remote user who is familiar with the environment. But what if the remote user has little knowledge about the environment?

Rao et al.[16] demonstrate that even for someone who do not know about the environment, they can still locate the camera view to a certain accuracies. In their study, Amazon Mechanical Turkers were recruited to perform a spatial location identification task (SpLIT) in which they were presented with a camera view of a location, and were asked to identify the location on a two-dimensional map under two reward schemes. In the ground truth scheme, workers were rewarded if their answers were close enough to the correct locations. In the majority vote scheme, workers were told that they would be rewarded if their answers were similar to the majority of other workers. Results showed that the majority vote reward scheme led to consistently more accurate answers. They visualized the points the Turkers chose on the floor map for each picture(see Fig. 5), it was interesting to note that most of the points were clustered around certain locations, although not all clusters were close to the correct location, which means that in most situations, the remote user does not need to be an expert, but can be anyone who can access to the map.

Once the error is detected, the remote side can click on "Adjust Map" (**B** in Fig. 3a) to move the arrow on the floor map from point **A** to point **B** and synchronize this changes to the local side.

Fig. 6: Illustration of Positioning Error Correction: after observing the inconsistence between the detected position and the real scene through the camera view, the remote user can correct the positioning error by dragging the arrow to where it should be

3.3.2 Spatial plan generation

One of the obstacles for implementing mobile indoor navigation systems is the difficulty to generate a detailed spatial plan for every building in advance. While large buildings usually provide floor maps at entrances or other salience spots, they may not be always available. So if an expert user can collaboratively work with the local user to sketch out a general spatial plan, it will help the user to have a good overview of the indoor environment. The workflow of this component is shown in Fig. 7.

The floor map can be either captured by the local user if he/she can find it within the building or by the remote user searching the web or even sketching out manually. The remote user then can interpret

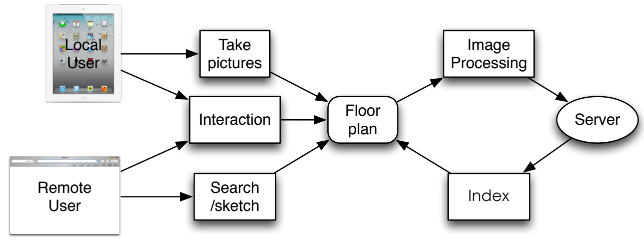


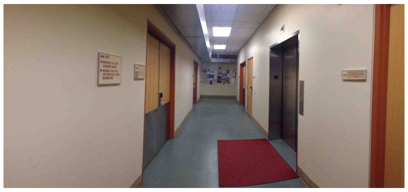
Fig. 7: The workflow of spatial plans generation: spatial plans can be generated by the local user to capture pictures or by the remote user to search the web or even sketch out, or by the interactions between both sides; then the spatial plan will be store in the server

the image by adding some labels (click "Add Labels" in **B** in Fig. 3a) onto some critical points that are meaningful to the local user. More importantly, the remote user can draw the routes for the local user by clicking "Draw Routes" **B** in Fig. 3a to show how to navigate from the start point to the destination. All those changes to the map should be appear on the local side in real time. On the other hand, the local user can interact with the remote side by double clicking anywhere on the map (See Fig. 8a) to alert the remote user to describe that point. The remote side should receive those requests (on top of Fig. 8b) and a blink point on the floor map (the question mark with a circle around in Fig. 8b) to remind him to add a label for that point. After the request is finished, the local user should see a new label on that point. By through all these process and interactions, a general spatial plan can finally be generated with critical landmarks and navigation routes that are really helpful for the local user to gain a general sense of the spatial layout of the environment. The resulting spatial plans will be uploaded to the server and restored in database along with the buildings location as index keys after the image is adjusted and processed, such that other users can retrieve it. These indices will be useful for multi-user scenarios, as well as for future users.

3.3.3 Collaborative guidance with AR interfaces

Besides the 2D map, the local user can also hold up the device to see through the camera view of the environment. In addition to the real scene, the objects corresponding to the labels or route points on the floor map within certain distance are superimposed onto the view. These objects are placed based on its distance and angle relative to the local user's current position and orientation. And the size of the virtual sign indicates the distance of that object, the further the larger. A 3D arrow (at the bottom) is also provided to indicate the direction to the next route point. As shown in Fig. 9a, the local user can clearly see that the elevator and the restroom are just on the right hand side and the room 3409 is just around the corner, and the 3D arrow also tells him/her to go straight to the route point #2. Furthermore, if the local user gets interested in some object in the view that is not present on the floor map, he/she can double click that object on the camera view to alert the remote user to make inference to associate the clicked object to its corresponding position on the map (as illustrated in Fig. 9a). And the remote side should receive request (as shown on top of Fig. 9b) and a blink area in his/her camera view to show that the local user wants to know where the corresponding object should be on the floor map. Then the remote user may respond to the request by adding a new label (assuming it is room 3408) to where the object should be on the floor map. After that a new virtual sign should be present in the camera view of the local device showing that the target object is room 3408 and it is just on the left hand side.

Besides augmented visual information, audio communication is provided as well to assist the interaction between the local side and the remote side particularly when the user is out of hands. The remote user can also send messages using the input area (as shown "Go Straight" on the bottom of Fig. 9b) to give instructions or other information then the local user can see the message as shown on top of

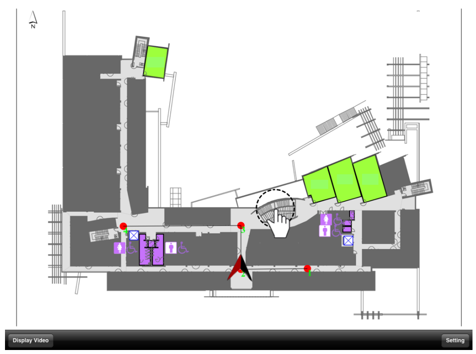


(a) The Picture to be Identified: the cues show that it's taken at a position near an elevator opposite to a door

(b) Clustering Analysis of Turkers' Performance under Ground Truth Scheme: the size of the circle presents the average inner distance for each cluster and the stroke width of the circles presents the percentage of points in that cluster

(c) Clustering Analysis of Turkers' Performance under Majority Scheme: the size of the circle presents the average inner distance for each cluster and the stroke width of the circles presents the percentage of points in that cluster

Fig. 5: Part of the results in Rao et al.' study[16]



(a) Local Side: the local user can double click anywhere on the device to send request to the remote user for identifying the point

(b) Remote Side: the remote user will be alerted to perform the task to add labels to describe the point sent from the local side

Fig. 8: Interaction between local user and remote user to generate spatial plans

Fig. 3c.

4 Conclusion and Future Work

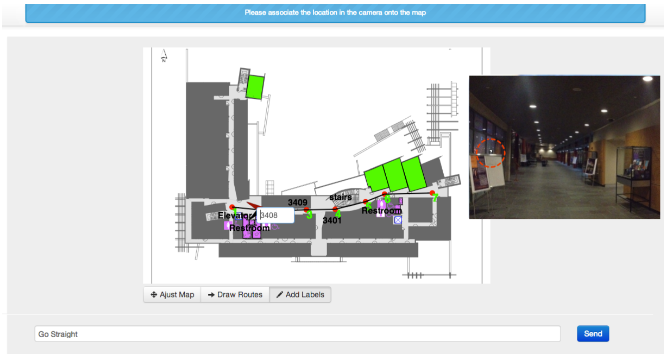
The proposed system is actually a combination of the autonomous system and human computation system, making the best of both their strengths, an autonomous system is good at calculating, displaying etc. while human is good at recognizing, perceiving, etc..To summarize, the current system has the following main features:

- By adopting the shared camera view, both of the local user and the remote user can share the same perspective, helping them establish anchors that allow them to both see and refer to the same location.
- The local user's position is first approximately estimated by the autonomous system then corrected by the remote expert using SpLT task such that the impact of the inaccuracy of positioning could be reduce to the least
- Multiple methods are provided to generate spatial plans including retrieving based on the location by the autonomous system, capturing, searching the web, collaboratively annotating or even scratching by the user.
- A simple touch-request-response paradigm makes the communication between the local user and the remote user more effective, encouraging them to interact with each other and perform the task faster.
- The information such as the labels, routes are augmented onto the real scene in the camera view based on their locations and angles relative to the local user's position, enhancing his/her perception of the new environment.
- Multimodal guidances including virtual signs, text messages and audio stream make the assistance more flexible to different application contexts.
- It is built as a mobile-browser application, which means that the remote side is rather extensible. This makes it much easier deployed to various consume applications.

As an attempt to build a reliable remote spatial assistance, there is still much that can do to extend our work:

- Perform systematic experiments to verify the degree to which it improves the local user's spatial cognition and helps him/her to navigate in indoor environments.
- The study[16] shows that even for someone who have little knowledge about the environment, they can still perform SpLIT at a certain accuracies. And Bernstein et al.'s work [2] also demonstrated that it's possible to utilize Amazon Mechanical Turkers to perform some tasks in real time. So it does point to a promising direction of research that incorporates Amazon Mechanical Turkers into our system as the remote user to assist the local user to navigate indoor. But there are still many challenges

(a) Local Side: the local use can double click anywhere in the camera view to send a request to remote user to associate the clicked object to what's its actual position



(b) Remote Side: the remote side will be alerted to perform the task of associating clicked area in the camera view to what it should be on the floor map

Fig. 9: Illustration of Collaborative Guidance

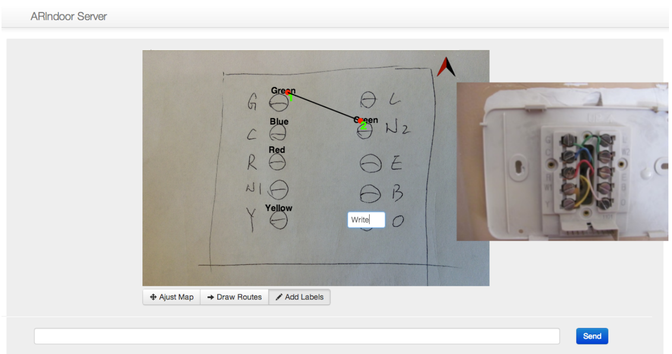


Fig. 10: Example of how to user the proposed system to fix a thermostat: the left picture is a schematic diagram drawn by the remote user and the right picture is the camera view shared from the local user

here, one is how to transfer those requests from the local user to Human Intelligence Tasks (HITs) such that they can be done by Turkers within a limited amount of time, the other is how to distribute the HITs to the Turkers who are able to perform better with high accuracy.

- Interestingly, we found out that our remote assistance system can be applied not only in indoor navigation but also some other spatial tasks, such as fixing thermostat. As shown in Fig. 10, the local user can transfer his/her view of the thermostat to the remote user. Meanwhile the remote user can sketch out a schematic diagram then synchronize it with the local user. In addition, the remote user can add some labels onto the picture to illustrate the key parts or draw lines to show what parts should be connected. The remote user can know about how the progress is going by seeing through the shared camera view when the local user is holding the device aiming at the thermostat. This is just a temporary solution for this task, there should be many other features implemented to extend this system to a general remote spatial assistance system.

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