SAT-Hub: Smart and Accessible Transportation Hub for Assistive Navigation and Facility Management

Zhigang Zhu[1], Jie Gong[2], Cecilia Feeley[2], Huy Vo[1], Hao Tang[1], Arber Ruci[1], Bill Seiple[3], Zheng Yi Wu[4]
[1]The City University of New York, USA
[2]Rutgers, The State University of New Jersey, USA
[3]Lighthouse Guild, USA
[4]Bentley Systems, Incorporated, USA
zzhu@ccny.cuny.edu, {jg931,cfeeley}@soe.rutgers.edu, {hvo@ccny, htang@bmcc}.cuny.edu,
Arber.Ruci@cuny.edu, wseiple@lighthouseguild.org, Zheng.Wu@bentley.com

Abstract

The goal of the proposed project is to transform a large transportation hub into a smart and accessible hub (SAT-Hub), with minimal infrastructure change. The societal need is significant, especially impactful for people in great need, such as those who are blind and visually impaired (BVI) or with Autism Spectrum Disorder (ASD), as well as those unfamiliar with metropolitan areas. With our interdisciplinary background in urban systems, sensing, AI and data analytics, accessibility, and paratransit and assistive services, our solution is a human-centric system approach that integrates facility modeling, mobile navigation, and user interface designs. We leverage several transportation facilities in the heart of New York City and throughout the State of New Jersey as testbeds for ensuring the relevance of the research and a smooth transition to real world applications.

1 Introduction

Travelers with disabilities often have lower tolerance to failure than normal travelers do, perhaps due to their increased perceived danger and the larger cognitive burden when travelling. To address some of the challenges, we propose an integrated and human-centered cyber-physical infrastructure framework that can effectively and efficiently transform existing transportation hubs into smart facilities that are capable of providing more efficient location-awareness and personalized navigation services to the traveling public. Although we initially aimed to develop indoor accessibility for underserved populations including those with BVI, ASD, mobility/hearing impairment and other cognitive disabilities, our goal is to develop universally accessible technology.

The CUNY-Rutgers-Lighthouse Guild joint research team, in close collaboration with our primary industrial partner Bentley Systems Inc. and three sectors of partners or potential investors in transportation agencies, service institutions and local government agencies, aims to bring Smart and Accessible Transportation Hub (SAT-Hub) service to all, with a focus on the needs of persons with disabilities. This will be achieved by tackling early technical challenges in integrating AI/machine learning, urban transportation management and user behaviors, undertaking customer discovery and understanding ethical and privacy issues, engaging users in development and students in education and training, and accelerating innovations through partnerships. We leverage several transportation facilities in the heart of New York City and throughout the State of New Jersey as testbeds for the proposed study thus ensuring the relevance of the research and the smooth transition and extension of the developed SAT-Hub to real world applications in cities with various scales in NY/NJ and elsewhere. During the period of research, we have interacted with people with a number of agencies – including NYC Port Authority, Metropolitan Transportation Agency (MTA), NJ Transit in both NYC and NJ, and NJ Passaic County for cyber infrastructure testbed selections. Our various partners operate the sites and all have great need to make their transportation hubs smarter and more accessible for people with disabilities living in and coming to the greater New York City metro area.

2. Background and Project Overview

2.1. Background and Related Work

The goal of the proposed project is to transform each large transportation hub into a smart and accessible hub (SAT-Hub), requiring minimal infrastructure change, to serve people with transportation challenges, such as passengers with visual impairment, mobility impairment, ASD, and other travel challenges. Although navigation services have been mature for outdoor environments with GPS and fully-equipped sensor packages on cars, indoor navigation still needs a breakthrough (Real *et al.*, 2019). Methods of indoor positioning have proposed the use of various technologies (Karkar & Al-Maadeed, 2018, Real et al. 2019), including but not limited to the use of cameras on smartphones or other mobile devices (Mulloni *et al.*, 2009, Caraiman *et al.*, 2017), passive RFID tags (Ganz *et al.*, 2012), NFC signals (Ozdenizci *et al.*, 2011), inertial measurement unit (IMU) sensors (Sato *et al.*, 2019) and Bluetooth Low Energy (BLE) beacons (Sato *et al.*, 2019, Murata *et al.*, 2019). Where passive RFID and NFC typically have significantly limited ranges (Ganz *et al.*, 2012) thus are limited to proximity detection, BLE beacon signals can be detected several meters or more away, allowing for localization based on signal strengths. Google Tango (which uses a 3D sensor and computer vision) has also been of interest (Li *et al.*, 2016); Kunhoth *et al.* (2019) provide a comparison of computer vision and BLE approaches.

Reliable indoor navigation services would connect the dots between various transportation modes, from mass transportation in inner cities to long distance public transportation vehicles such as airplanes, busses and trains. Furthermore, integration of crowd dynamic information with 3D static information is the first-of-its-kind work and key to providing customized paths for people with travel and mobility challenges. Our solution could also be extended to indoor navigation of other public facilities, such as school buildings, libraries, office buildings, etc. The societal need is significant, particularly for those city dwellers with disabilities who want to have the independence in travel.

We have particularly identified two groups who have travelling challenges: people with BVI and ASD. In the US alone, 6.6 million people are BVIs, while 1 in 45 people have been diagnosed with ASD. They have similar challenges in finding places and identifying orientations, but their needs are also uniquely different, therefore we mainly use these two groups to design our services with adequate user interfaces. For BVI people who lack visual perception, accurate localization, route accessibility, and auditory and vibrotactile interfaces would be the keys, while for people with ASD who face cognitive and sensory-overloading challenges, crowd detection, visual interfaces and adequate verbal commands would be need be to carefully considered (Nair *et al.*, 2018a, 2018b). We also need to consider the ethical and privacy issue when they use tracking and sensing technologies. With universally accessible design principles, we hope the services will be broadly inclusive and applicable to other groups as well. Based on a report by NYC Mayor's Office for People with Disabilities (MOPD) (MOPD, 2017), there are almost 1 million New Yorkers who self-reported that they are living with a disability, or roughly 11.2% of the city's population. MOPD also estimates that approximately 6.8 million visitors to our city each year have a disability. We envision that the major transportation facilities and public/private facilities will adopt the solution and we foresee that there could be an ADA (Americans with Disabilities Acts) Compliance requirement that every facility will need such services. The societal and economic impact comes from three areas (1) the improvement of operation efficiency; (2) the increase of volumes of customers (passengers); and (3) the increase of travel independent of people with disabilities.

2.2 Project Overview

The SAT-Hub project started with a DHS Summer Team Research project on data analytics, evolved into a NIST Global Cities Team Challenge (GCTC) Action Cluster (Gong *et al.*, 2017), and through an NSF Smart and Connected Communities (S&CC) planning grant, developed into an NSF Partnership for Innovations (PFI) project. We propose an integrated and human-centered cyber-physical infrastructure framework that can effectively and efficiently transform existing transportation hubs into smart facilities that are capable of providing better location-awareness and personalized navigation services (e.g. finding terminals, improving travel experience, obtaining security alerts) to the traveling public. Although we initially developed this for underserved sensory and cognitive loss or challenging populations, the system will enhance universal access. With our interdisciplinary background and collective synergies in urban systems, infrastructure engineering, sensing/data analytics, accessibility considering perceptual/cognitive human factors, and paratransit services, the SAT-Hub project will overcome three main technical challenges (Figure 1):

(1). ***A multilayer live facility model (LFM)***, with four layers: a building feature layer, a space information layer, a crowd dynamic layer, and a service information layer. Privacy issues shall be dealt with in the AI-based crowd counting component with surveillance cameras.

(2). ***Hybrid mobile localization (HML) algorithms***, using beacons, 2D/3D cameras and onboard sensors, integrated with the information from the 4-layer LFM. Since onboard sensors and cameras will be used as users' "eyes", ethical and privacy concerns need to be addressed.

(3). ***Multimodal human-centered interfaces (MHI),*** with both the LFM and HML as the drivers for users with disabilities and/or travel challenges to better understand their needs and gaps. We aim to provide users unobtrusive and inclusive interfaces with universal design principles.

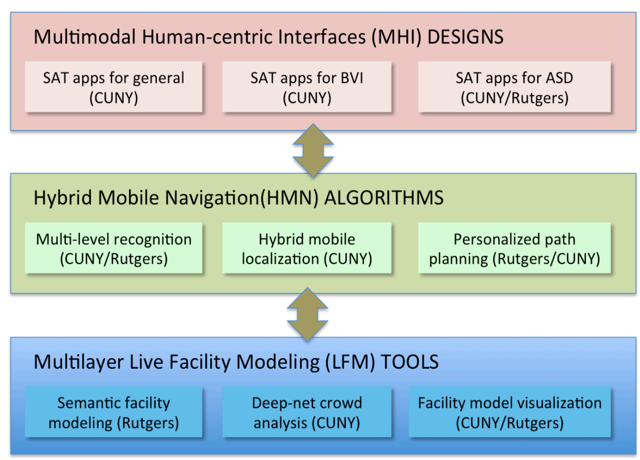

Figure 1. A system diagram of the planned scope of functionality. The roles of the research institutions are listed.

3. Current Research Results

For an overview of the project, see a demo video[1]. Here we highlight four pieces of AI related research results up to date that contribute to the SAT-Hub project for social good.

[1] https://youtu.be/KXZnxyA30KM

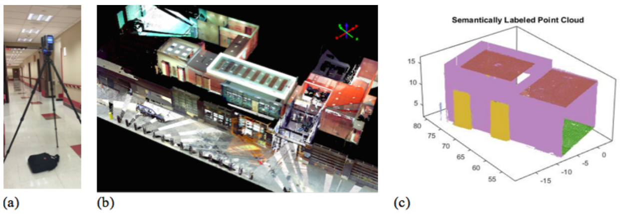

Figure 2. (a) Facility modeling with lidar; (b) Colorized point cloud data of the facility; (c) Point clouds with dense annotation of building elements (in this case, elevator doors).

3.1. 3D Modeling and Understanding

We propose to use reality capture technologies such as terrestrial LiDAR to create high-fidelity 3D facility models (Figure 2) as the foundation for indoor semantic modeling for navigation. The collective outcome of reality capture and indoor semantic modeling is a facility model with multiple data layers optimized for localization and wayfinding applications. We will further enrich the model into a live facility model by infusing dynamic contents such as crowd movement and space and service changes due to maintenance, disruptions, and other unexpected incidents. To alleviate the cost of collecting and annotating large-scale point cloud datasets, we propose an unsupervised learning approach to learn features from unlabeled point cloud "3D object" dataset by using part contrasting and object clustering with deep graph neural networks (GNNs) (Zhang, 2019; Zhang & Zhu, 2019). The contrasting learning step forces a ContrastNet to learn high-level semantic features of objects but probably ignores low-level features, while the ClusterNet in the clustering step improves the quality of learned features by being trained to discover objects that probably belong to the same semantic categories by using cluster IDs. We have conducted extensive experiments to evaluate the proposed framework on point cloud classification tasks. This work will be useful in 3D object recognition and segmentation in facility modeling and assistive navigation especially for BVIs to identify traversability and obstacles.

3.2. Crowd Analysis using CNN and GAN

A new method in using deep convolutional neural networks (CNN) for crowd analysis with little labeled data (Olmschenk, 2019, Olmschenk *et al.,* 2019). We have used a generative adversarial network (GAN) to train crowd counting networks using minimal data, studied how GAN objectives can be modified to allow for the use of unlabeled data to benefit inference training in semi-supervised learning. More generally, we explained how these same methods could be used in more generic multiple regression target semi-supervised learning, with crowd counting and crowd density map estimation being an application example (Figure 3). Given a CNN with capabilities equivalent to the discriminator in the GAN, experimental results show that our GAN is able to outperform the CNN even when the CNN has access to significantly more labeled data. This presents the potential of training such networks to high accuracy with little data. This greatly facilitates the success of using CNNs in crowd analysis across many surveillance and transportation cameras, with limited labeled data for providing valuable information for transportation facility management and assistive navigation. Crowd analysis is particularly valuable for helping people with ASD to avoid sensory overloading when encountering a heavy crowd.

Figure 3. Crowd density estimation in front of elevators.

3.3. Personalized Entire Route Planning

Route planning is a prerequisite to ensuring appropriate navigation for everyone, but can be significantly more involved for pedestrians with BVI and ASD. Previous studies primarily targeted the micro-navigation after the determination of routes for the outdoor travel. This work tries to optimize the initial indoor route selection prior to the orientation. A routing optimization model (Wang *et al.,* 2019) is proposed involving two situations - fixed-order and random-sequence activities - to address the important issue of macro-navigation. Further, novel travel utility functions are defined to represent the personalized travel requirements considering travel confidence, different types of route segments and the acceptable level of travel difficulty. Finally, the performance of the proposed model is verified based on the real case of a bus terminal in New York City under a number of scenarios. The results showed that the visually impaired pedestrian could make a detour to select a longer but less difficult path. Preliminary research indicates similar preferences for other pedestrians with disabilities, specifically ASD and mobility impairments. This personalized rout planning methodology fills the research gaps on the customized route selection for macro-navigation and supports inclusive AI for people with disadvantages.

3.4. Hybrid Localization for Assistive Navigation

Blind and visually impaired (BVI) individuals and those with Autism Spectrum Disorder (ASD) face unique challenges in wayfinding in unfamiliar indoor environments. ASSIST (*Assistive Sensor Solutions for Independent and Safe Travel*) is an indoor navigation app that guides a user to navigate with high accuracy while augmenting a user's understanding of his/her environment (Nair *et al.*, 2018a, 2018b). The app has three modules: a hybrid indoor localization program that uses BLE beacons and Google Tango to provide high accuracy, a body-mounted camera to provide the user with momentary situational awareness of objects and people, and map-based annotations to alert the user of static environmental characteristics. ASSIST also features personalized interfaces by taking into account the unique experiences that both BVI and ASD individuals have in indoor wayfinding and tailors its multimodal feedback to their needs (Figure 4). Using the ASSIST system, two pilot studies have been performed with human subject tests with both BVI and ASD. Currently on a whole array of app de-

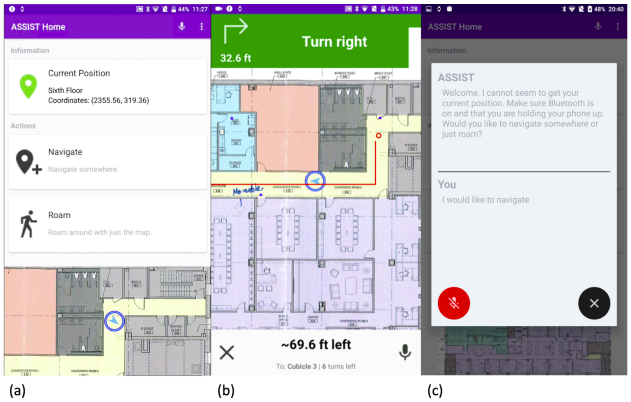

Figure 4. Interface screens for ASSIST. From left to right: (a) home screen, (b) navigation interface, (c) voice engine interface.

velopment for indoor navigation (Tango 3D sensor, ARKit for iPhones, ARCore for Android phones, VR-based pre-journey training), now testing at CUNY (Chen *et al.*, 2019, Venerella *et al.,* 2019). While the apps track users' locations and take pictures of their scenes, the data are not saved for minimizing both ethical and privacy concerns.

4. Testing, Training and Outreach

4.1. Testbeds, User Tests and Surveys

A testbed is being developed as a first prototype of the SAT-Hub framework with 3D modeling, cloud services and app development at the headquarters of Lighthouse Guild, a not-for-profit institution serving BVIs. We have performed three rounds of human subject tests at Lighthouse Guild on ASSIST app (Nair *et al.*, 2018a, 2018b) with both visually impaired users and users with ASD as well as persons without disabilities, a total of 23 users. These include a performance study to collect data on mobility (walking speed, collisions, and navigation errors) while using the app, and a perception study to collect user evaluation data on the perceived helpfulness, safety, ease-of-use, and overall experience while using the app. Readers may view a demo video showing ASSIST's system components and human subjects testing through this YouTube link[2]. We also did a focus group study at Goodwill NY/NJ with 18 ASD individuals for their feedback on using smart navigation and VR training apps (Tang *et al.*, 2020). A prototype viewer for integrating building scan data with GIS information is being developed at Rutgers. The next step is adding dynamic data such as service information into the viewer. Data collection at NJ Transit Train Station in New Brunswick as a small-scale testbed was partially done. We mapped the exterior surrounding of the facility and fused lidar with video data for traffic monitoring (tracking and quantifying moving objects). We will continue on the modeling of the interior (the station platforms). This will increase our understanding of the unique challenges and opportunities in a real transportation facility.

[2] https://youtu.be/Hq1EYS9Jncg

4.2. Workforce Training

Both graduate and undergraduate students are involved in algorithm/system development and human subject tests. At CUNY, one PhD student is engaged in the system architecture design and crowd analysis algorithm development, and his PhD thesis (Olmschenk, 2019) has been successfully defended. Two new PhD students have started working on navigation and people detection, respectively. One master student worked on her thesis on 3D object recognition and 3D scene segmentation (Zhang, 2019). More than half of the 24 undergraduate seniors in CUNY's capstone class *BEAT: Branding and Entrepreneurship of Assistive Technology for Social Good,* have been involved in mapping and app development. At Rutgers, two PhD students have been participating in the 3D modeling of the test sites and developing personalized route selection algorithms. We have both graduate and undergraduate students involved in the SAT-Hub project not only training them in new AI and machine learning skills in a real world setting, but also raising their awareness of using AI for common good.

4.3. Partnership Development

The Workshop on Smart and Accessible Transportation Hub (supported by Bentley and NSF S&CC) was held on December 7, 2018 at Lighthouse Guild with attendees from NSF, Bentley, CUNY, Goodwill, Lighthouse Guild, Port Authority NYNJ, NYC MOPD, NYSCB, NJ Passaic County, Rutgers and other institutions. The goal was to better understand the needs from both transportation agencies and users in terms of both security and transportation. The apps our team developed were also tested by attendees and received very positive feedback. Again the students were fully involved in the discussions and interactions.

5. Conclusion and Discussion

With community engagement, we have learnt: (1) Both BVI and ASD users and service providers like to see the apps in use with their smartphones, most preferably iPhones. (2) BVIs enjoy the high accurate in localization, but ask for more sematic and object information. (3) ASD users prefer succinct visual interfaces and apparently need different sets of vocabulary for the verbal commands depending on their levels of cognitive functionalities. The planned activities as the next step include: (1) refinement of integrative research themes of AI, user studies and applied domain knowledge to enable deployment of a useful solution for social good; (2) customer discovery and are identifying patentable technologies that can be transferred to industry applications; and (3) consideration of ADA compliances for public buildings in accessibility with new technologies in smart devices and artificial intelligence.

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