NSF ExLENT Pivots Track, An End-to-End Mixed Reality System to Facilitate Latinx With Cognitive and Mobility Impairments in the Construction Industry.

Proposal submission on FastLane.nsf.gov [DEADLINE: September 14, 2023.]

- ☐ Project Summary [One (1) page max].
- ☐ FastLane documentation
  - ☐ Collaborators and other affiliations
  - ☐ Current and pending support
  - ☐ Bio sketch
  - ☐ Budget
  - ☐ Data management
  - ☐ Equipment and facilities
  - ☐ Sub-award documentation

Project Description. -Fifteen (15) pages max-

- ☐ Project Overview, Rationale and Importance (1 page) - SONIA
- ☐ Experiential Learning Activities (1.5 pages)
- ☐ Partnerships (2 pages)
- ☐ Building Community via a Cohort Model for Participants (1 page)
- ☐ Building an Inclusive and Diverse STEM Workforce (1 page)
- ☐ Sustainability and Scalability (1.5 page)
- ☐ Evaluation (1.5 pages)
- ☐ Generation of Knowledge (1.5 page)
- ☐ Broader Impacts (0.5 page)
- ☐ Results from Prior NSF Support (0.5 page)

Others

- ☐ References Cited
- ☐ Budget
- ☐ Facilities, Equipment and Other Resources
- ☐ Data Management Plan
- ☐ Mentoring Plan (up to 2 pages)
- ☐ Letter of Collaborations

Project summary

1 Overview

This ExLent project examines and tests the functional and technical basis of an end-to-end collaborative platform (AutoVideo) to allow persons with disabilities (PWDs) to telework in construction management, safety, and quality assurance. Developing an integrated End-to-End Mixed Reality System to Facilitate Latinx With Cognitive and Mobility Impairments in the Construction Industry requires collaboration from various disciplines. The team has organized a highly interdisciplinary team to identify relevant areas of opportunity in computer vision techniques, mixed reality, and semi-autonomous robotics to improve access to work for PWDs. In Phase 1 the team has organized ten investigators from seven universities, two industrial collaborators, an assistive technology advisory board, and an IP-strategy advisory panel to use **design thinking** to empathize, define, and ideate while building an open-source platform for rapid prototyping and testing a minimum viable **prototype**. Phase 1 will set the stage for phase 2 to create a higher-fidelity minimum viable **product** using an iterative **lean** approach based on a build-measure-learn iterative work to help this team get AutoVideo to PWDs' hands faster. At the onset of Phase 2 (March 2026), the team will have de-risked the technology enough to reach out to external private investors.

2 Intellectual Merit

This project will develop an open-source sandbox platform for rapid prototyping to expand the fundamental understanding of computer vision, mixed reality, and robotics to provide practical computational tools in dealing with an emerging and critical telework for PWDs with significant industrial applications. The team has previously developed the highly praised open-source package AutoKeras, the #1 automated deep learning software on GitHub with over 8,600 stars in 1,400 forks. The team plans to build upon such a platform and develop a fast-prototyping and knowledge repository platform to be a reference for the PWD community and the future of work, but also to share the research tools, data, design requirements, simulations, models, and findings emerging from this project. The team envisions this will accelerate the development and integration of these technologies and enable a diverse community of researchers, technology developers, practitioners, and industry to leverage our efforts as more advanced technologies continue into the construction industry and other work domains. We also foresee this effort as enabling us to serve as an educational focal point for training the next generation of assistive technology developers and future workers in construction.

3 Broader impacts

This project's results will have an immediate and substantial social impact on improving the job opportunities for PWDs. The proposed open-source sandbox for fast-prototyping will allow the team to understand persons with mobility and cognitive impairments need to better design telework tools to enable on-site jobs in the construction Industry that were previously not available for them. At the same time, successful human-technology partnerships can effectively enhance human performance to simplify excessive amounts of data into actionable items to boost construction safety while leading to higher product quality.

NSF ExLENT Pivots Track. An End-to-End Mixed Reality System to Facilitate Latinx With Cognitive and Mobility Impairments in the Construction Industry.

Construction is one of the most dangerous industries in the United States. Construction workers routinely perform dangerous tasks in complex and stressful environments correlated to critical consequences, including serious injuries and even death. For instance, while construction workers represent 7.7% of the US workforce, they suffer more than 22% of the nation's reported work injuries [1]. In 2021 alone, the US Bureau of Labor Statistics ranked construction as the deadliest industry in America, recording 1,008 fatal events (almost three fatal work injuries a day) and 174,100 injuries resulted in a major disability **(mobile impairment being one of the most common)**, which resulted in over 11.5 billion in financial losses for this industry [2]. **This convergence accelerator project examines and tests the functional and technical basis of an end-to-end collaborative platform (AutoVideo) to allow Persons with Disabilities (PWDs) to work in construction management, safety, and quality assurance. AutoVideo aims to explore emerging technologies such as Machine Learning (ML) computer vision, mixed reality, and semiautonomous robots to define emerging job opportunities for emerging teleworkers Fig. 1.**

Studies show that because of how highly dynamic the environment is in this industry, construction workers are constantly required to perform highly demanding physical activities and make complex decisions under unstructured and time-constrained scenarios daily, which results in repeated exposure to physical and environmental stressors that are directly correlated to a decline in cognitive function [3,4]. In turn, such a worker's cognitive reduction in the workplace is a hazard that affects the ability to think clearly and respond appropriately, leading to the serious workplace injuries mentioned above [5]. **To further amplify such challenges, while PWDs face acute accessibility barriers when trying to return to their previous on-site work, the construction's labor shortage is only expected to worsen in the coming years [6]**. Therefore, there is a critical need for a tool to enable work environments for PWD while making safer workplaces in the construction industry.

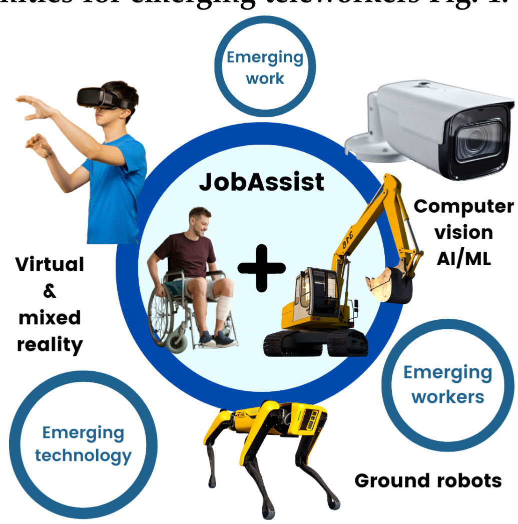

Figure 1: AutoVideo, our proposed convergence accelerator platform, will be the foundation for the construction industry to enable access to PWD to work while increasing safety at the worksite.

Workplace digitalization technologies present a unique opportunity to transform the construction industry, enhance job access to PWDs, while making the on-site work dramatically safer. Digitalization and automation of work technologies such as computer vision, virtual reality, and robotics can greatly transform the landscape of construction work and improve the safety, performance, and quality of life of PWD working in construction. **Computer vision** can significantly increase the return on investment for building enterprises. For instance, trained object recognition models can determine if employees use safety gear like hard helmets, vests, or masks while at work. These artificial intelligence (AI)-enabled technologies can be deployed, controlled, and operated through human-machine interfaces, including cutting-edge interfaces made possible by **mixed reality**, which remote workers can utilize to improve team planning, cooperation, and decision-making under pressure. Consequently, augmenting technologies is expected to influence both the job and the employee significantly. **Semi-autonomous ground robots** that are remote-operated

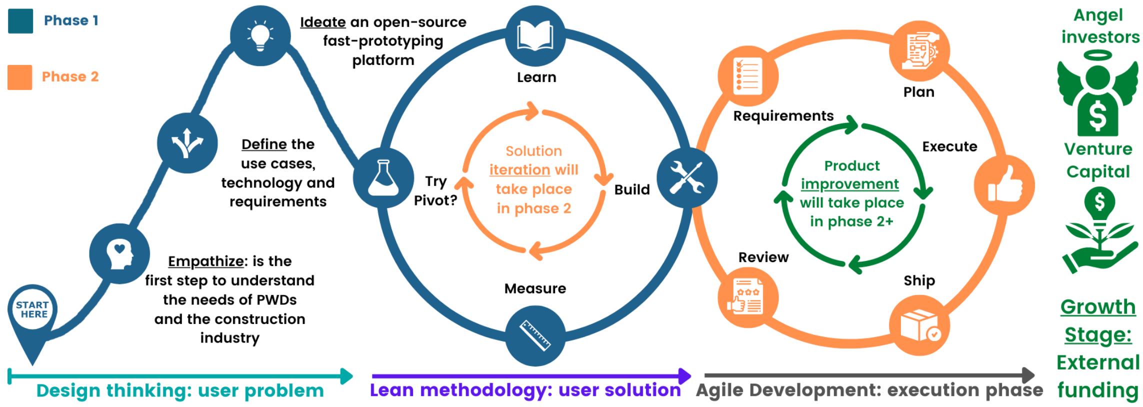

Figure 2: Our phase 1 work will use design thinking to empathize, define, and ideate while building an open-source platform for rapid prototyping and testing a minimum viable **prototype**. We want to highlight that we are open to the possibility of pivoting on our initial value proposition assumptions, if justified with data. Phase 1 will set the stage for phase 2 to create a higher-fidelity minimum viable **product** using an iterative lean approach based on a build-measure-learn iterative work to help this team get AutoVideo to PWDs' hands faster. At the onset of Phase 2 (March 2026), the team will have used Agile development to mature AutoVideo and de-risk the technology enough to reach out to external private investors.

can potentially aid in the construction process and add safety to the on-site workers.

However, even though AI, virtual reality (VR), and robotics present a unique opportunity to transform the construction industry, assistive technologies still need to be affordable and accessible to truly have an immediate impact on a population that urgently needs such interventions to be part of the construction workforce for the greater benefit of society. One example is the use-inspired request from the predominant Latinx construction workforce in states such as California, Texas, and Florida. Additionally, we believe that PWD-specific assistive technology and accessibility tools will eventually scale to other domains, such as manufacturing, and to help other members of society, such as the elderly or even individuals and families in need of telework temporarily. Since each implementation domain will require its technical requirements and specifications **there is a great need for a fast-prototyping platform, and product-market needs learning to effectively identify the user needs to formulate value propositions for the emerging workplace digitalization field properly.**

In terms of context-sensitive technology capabilities, necessary learning, or successful integration with existing worker experience and skills particular to construction workers, none of the augmentation capabilities listed above are easy. Because digital technologies, semiautonomous robots, and human agents must learn and adapt to each other in highly dynamic environments, there must be principled team methods that future technology development and industry partners may use to promote efficient and safe building work. While current VR-based construction platforms are heavily focused on on-site mapping progress [7], there is a critical gap in integrating emerging augmentation technologies into remote work in such a way that an individual or a group of users can learn and collaborate optimally in tomorrow's human-robot teams.

We intend to complete this project in two stages, as seen in Fig. 2. First, we want to construct an open-source rapid prototyping platform in Phase I based on a combination of design thinking and lean methodology to evaluate an AI-enhanced mixed reality for the workplace (**AutoVideo**) that incorporates a succession of very-low-resolution prototypes. Phase I will also focus on assembling a well-connected interdisciplinary team of occupational therapy professionals, data scientists, civil engineers, and industry stakeholders to guarantee that AutoVideo v0.1 is extremely relevant to people with disabilities and the construction sector. Then, in Phase II, we will create AutoVideo v1, a minimum viable product (MVP) derived from the Phase 1 rapid-prototyping platform that will improve the prototype system to a functional system to fulfill the demands of PWDs and the construction industry. Both AutoVideo v0.1 and AutoVideo v1 will require the integration of feedback from PWDs and construction workers. If successful, the high-resolution AutoVideo should be extendable to multiple tasks performed on construction sites, such as worker training, safety assessment, quality assurance, and project management. Some of the questions from the NSF Convergence Accelerator Workshop, held in May 2021, we anticipate answering with our proposed fast-prototyping platform, and customer discovery activities include:

- □ What roles will AI, digitalization, biometrics, robotics, automation, and big data play in the design of enabling tools?
- □ Will smart and connected home technologies allow PWDs to work from home (solving their work commute challenges) as effectively as they can from an office environment?
- □ How will we measure the overall benefits of integrating PWDs in society?

1 Project Overview, Rationale and Importance

The project partners are companies that are related to the construction industry, contractors, developers, final users of the facilities, academics, and laboratories such as Data to Knowledge Laboratory from Rice University. The project will consist in an immersive two months course-based industry-driven problems program.

The rationale of the project is to reconnect people that has lost physical mobility due to the construction work, using its expertise but using a new tool of emerging technology. Construction is one of the most dangerous industries in the United States. Construction workers routinely perform dangerous tasks in complex and stressful environments correlated to critical consequences, including serious injuries and even death. For instance, while construction workers represent 7.7% of the US workforce, they suffer more than 22% of the nation's reported work injuries [1]. In 2021 alone, the US Bureau of Labor Statistics ranked construction as the deadliest industry in America, recording 1,008 fatal events (almost three fatal work injuries a day) and 174,100 injuries resulted in a major disability **(mobile impairment being one of the most common)**, which resulted in over 11.5 billion in financial losses for this industry [2]. **This project examines and tests the functional and technical basis of an end-to-end collaborative platform (AutoVideo) to allow Persons with Disabilities (PWDs) to work in construction management, safety, and quality assurance. AutoVideo aims to explore emerging technologies such as Machine Learning (ML) computer vision, and semiautonomous robots to define emerging job opportunities for emerging teleworkers Fig. 1.**

The construction industry is suffering a mismatch of labor supply with the construction work demand. The average age in the construction industry is 42.1 years old. For every 5 people that retire today, only 1 joins the construction workforce. Demand in the construction industry is increasing while supply is decreasing.

According to McKinsey report, by late 2021, project owners were reporting that up to 25 percent of material deliveries to sites were either late or incomplete affected by those labor mismatches in all the supply chain. In project execution, the combination of higher hourly rates, premiums and incentives, and overtime payments was resulting in overall labor costs as much as double prepandemic levels. Meanwhile, difficulty accessing skilled and experienced people was leading some owners to report project delays related to issues around the quality and productivity of on-site work.

The importance of the project is that we will be attacking three problems, labor mismatch in construction industry, the lack of opportunities for PWD after an accident in construction related work and the lack of access of PWD to emerging technologies. Our immersive two months program, will prepare or give tools so that the PWD that will be taking our program can pivot to a new role off-site and learn new skills in the emerging technology such as data preprocessing and labelling, while getting trained to be hired by the companies.

We have developed a novel digital representation of the construction site that will help PWDs access new job opportunities by interacting with a computer-enhanced environment and other users. Developing an integrated End-to-End Mixed Reality System to Facilitate Latinx With Cognitive and Mobility Impairments in the Construction Industry requires collaboration from various sources and disciplines. It also requires changing from a system prone to silos to one designed to share and open-source early designs, so customer feedback is integrated quickly. In addition, we envision this platform integrating computer vision techniques with mixed reality and mobile robotics. Thus, we need a highly interdisciplinary team to identify relevant areas of opportunity to improve access to work for PWDs. We will support activities encouraging scientists from different disciplines, including AI experts, gaming, assistive technologies, construction, and robotics. Our PI, Co-PIs, and senior personnel have a wealth of knowledge and experience in the field and several ongoing partnerships from previous and existing projects. Below are some examples of particularly pertinent and synergistic work that our team will use in this proposal.

Dr. Costilla co-led an effort to build AutoVideo a computer vision system for video applications. Action recognition is an important task for video understanding with applications to this project. However, developing an effective action recognition solution often requires extensive engineering efforts in building and testing different combinations of the modules and their hyperparameters. AutoVideo is part of our preliminary work for automated video action recognition to transform actions in the construction site into the digital domain. AutoVideo offers the following advantages for our target users in this convergence accelerator proposal: 1) highly modular and extendable infrastructure following the standard pipeline language, 2) an exhaustive list of primitives for pipeline construction, and 3) an easy-to-use User Interface.

Dr. Du has led several Mixed Reality + semi-autonomous efforts funded by federal agencies to develop reality capture and sensory augmentation technologies for first responders. The technologies developed by his team can model and render complex sites in real time. Coupled with computer vision and point cloud registration algorithms, the systems can grant first responders augmented situational awareness, such as "seeing through walls" ability. This project poses unique challenges for physically and cognitively impaired users. Dr. Du's previous experience with special technologies development and user studies will set a solid foundation for this work.

Dr. Collins was the co-principal investigator of the NSF Grant titled "Quality of Life Technology RERC", where she led focus groups of consumers with disabilities or of those who were aging, to translate the perspectives of these consumers to the Carnegie Mellon engineers to provide input in their creation of smart technologies. One such technology was the Personal Mobility and Manipulation Appliance (PerMMA), a robotic arm mounted on a power wheelchair to assist its users in essential mobility and manipulation tasks.

Dr. Shipman efforts include the design, development, and evaluation of the Sign-Language Digital Library (SLaDL) that he developed based on an analysis of limitations of existing technology for the sign language community and the application of video analysis and action recognition to improve information access for the hearing impaired. His expertise in domain modeling and understanding user communities will be valuable to the proposed work.

Among our industrial partners is **Dr. Timothy Becker and Pedro Ibanez** who bring valuable experience from the construction industry, his deep expertise in worker training, and their support to access construction sites facilitated by Bartlett Cocke and Kiewit respectively, will help us guide the developments of our user-inspired developments.

In the same way, the PI and Co-PIs have already approached **Dr. Saurabh Biswas and Mr. Jim O'Connell** at the technology transfer offices at Texas A&M and the University of Florida, respectively, where they provide professional advice to industry-academy partnership on their IP strategy. **We believe that by including IP strategy veterans from day 1 of Phase 1, our team will better position our proposed work to create IP with true market value.**

2 Experiential Learning Activities

3 Partnerships including a Roles and Responsibilities Table

Our team consists of ten investigators, seven universities, two industrial collaborators, an assistive technology advisory board, and an IP-strategy advisory panel. The team is accordingly organized with deep and cross-cutting experience in focus groups of consumers with disabilities, AI, mixed reality, and robotics and has multiple ongoing collaborations through past and current projects directly related to the proposed work. We want to highlight that the host institution, in particular, has extensive experience designing and delivering products and expertise with **raising capital from outside investing groups (venture capital and angel investors)**. In the same way, our University partners at the University of Florida, Texas A&M University, Rice University, and The University of Texas Medical Branch **will provide us with the fundamental and translational research understanding** that will be crucial when proposing a platform for PWD working in the construction industry. Finally, large companies as well as our advisory board **will provide technical and marketing feedback, business coaching, and access to facilities and other resources.**

Co-PI Alfredo Costilla-Reyes was previously an investor partner at Kirchner group and is currently the Chairman and Chief Technology Officer at AIPow LLC, a Hispanic-led and venture-funded company established in Texas that has its origin in academia and the open-source community. He will oversee the project, manage the accounting, and be the initial point of contact for the different stakeholder groups. Dr. Alfredo will also be in charge of coordinating the customer discovery and business strategy work.

Co-PI Diane M. Collins is an Associate Professor in the Department of Occupational Therapy at the UTMB School of Health Professions. She will help us lead the study groups with the person with cognitive and mobility impairments interviewed during this project.

Co-PI Eric Jing Du is an associate professor in the Department of Civil Engineering and the Department of Industrial and System Engineering at the University of Florida. Before joining academia, he was an engineer at Zachry Industrial in San Antonio, TX, and Kiewit Offshore Services in Corpus Christi, TX. He will be in charge of our effort in the area of human-robot collaboration and automated construction operations.

Co-PI Frank Shipman is a Professor in the Department of Computer Science at Texas A&M University. He will help us test our computer-supported cooperative work, multimedia, and intelligent user interfaces.

Senior Personnel. Xia (Ben) Hu is an Associate Professor at Rice University in the Department of Computer Science and the Director of the Data-to-knowledge (D2K) Lab at Rice Univerity. His highly successful open-source work in machine learning automation and explainability will be essential for him to lead our open-source sandbox efforts.

It is important to highlight that the team has shown strong synergy by collaborating on differ-

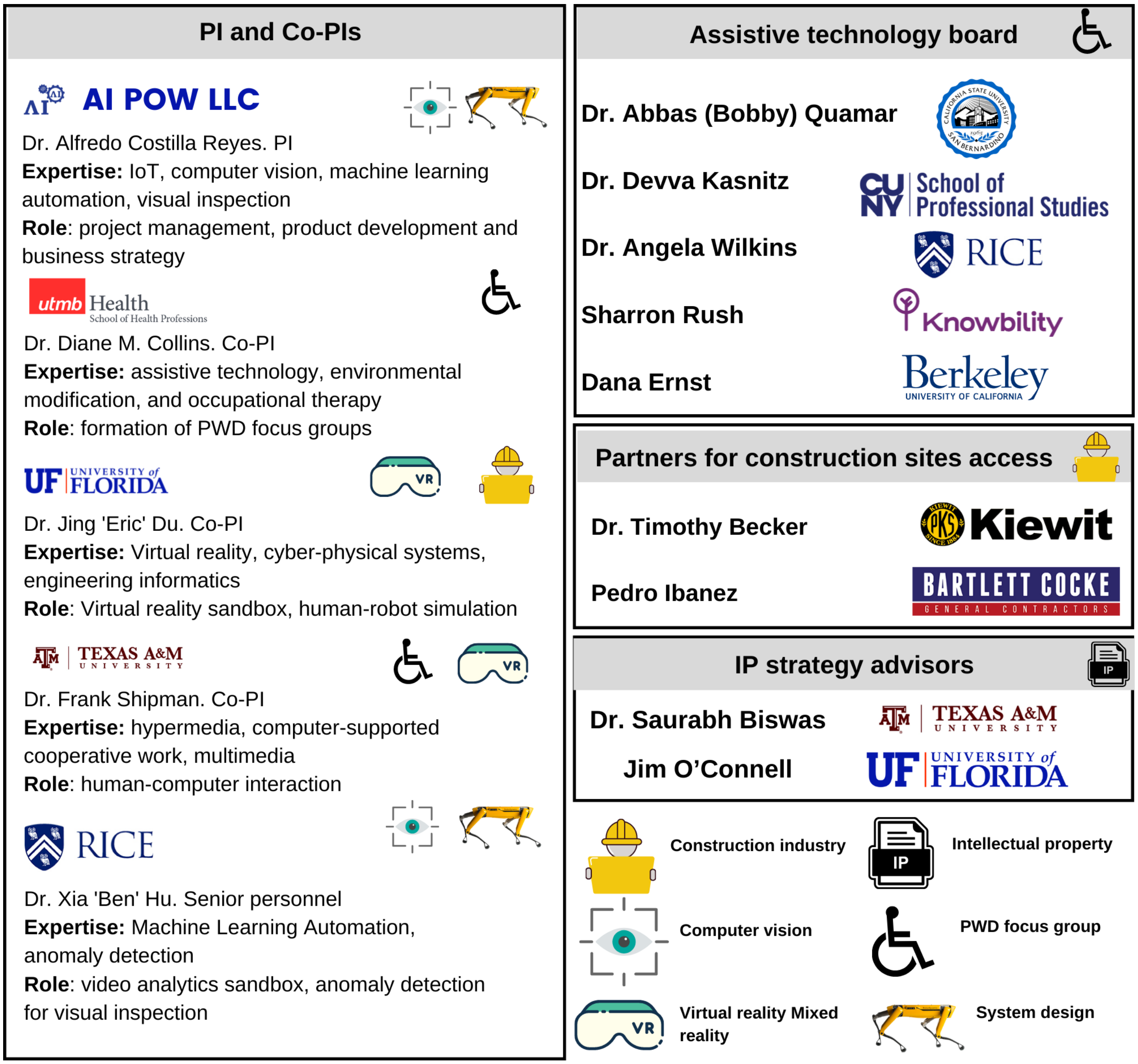

Figure 3: Table of our interdisciplinary partnering team consisting of seven universities, an assistive technology board, and two construction industry partners and IP-strategy advisors.

ent DoD and industrial projects and co-authored publications in fundamental research in developing interpretable, automated, and interactive machine learning systems.

3.1 Supporting partnerships

Technology requirement identification and assistive technology development panel

Abbas (Bobby) Quamar, PhD is an Associate Professor at the Department of Special Education, Rehabilitation & Counseling at the California State University San Bernardino. Dr. Quamar has substantial work experience in various health and rehabilitation settings, from hospitals to sporting clubs. He will provide metrics on how to evaluate the effectiveness of our assistive technology in promoting independence for people with disabilities.

Devva Kasnitz, PhD is an Adjunct Professor at the City University of New York, School of Professional Studies. She was on the founding boards of the Society for Disability Studies, the Anthropology and Disability Research Interest Group, and the Association of Programs for Rural Independent Living. Dr. Kasnitz will be our point of contact to reach our to PWD for our study groups and our main mentor for our customer discovery activities.

Sharron Rush is the co-founder and Executive Director of Knowbility a nonprofit advocacy, consulting, and training company based in Austin, Texas. Her work at Knowbility includes policy review, performance analysis, technical consultation, and training development for private and public companies, government agencies, and schools. Her technical expertise, and understanding of the barriers faced by people with disabilities, will be key to finding the use cases and technology requirement identification of our objective #1 as well as to our point of contact to reach out to end-user and partnership expansion of our objective #3 described in Section 4.

Angela Wilkins, Ph.D. is the Executive Director of the Ken Kennedy Institute. Her collaboration in this proposal will be critical as she will provide regular feedback from the industry expert perspective. Dr. Wilkins will also be a mentor for our planned customer discovery activities.

Dana Ernst is a researcher at UCLA (Cultural/Linguistic Anthropology) and a Fellow at the UC Berkeley Disability Laboratory. Her expertise includes incorporating and analyzing nonverbal cues and communication accompanying speech in interviews with PWDs. Her focus on research and development involving PWD stakeholders from the start and her connections to researchers, practitioners, educators, and PWD communities will be crucial during Phase 1 and 2 activities.

Industry partners:

Timothy Becker, Ph.D. is the Director of Learning at Kiewit Corporation. Dr. Becker will bring valuable experience from the construction industry, and his deep expertise in worker training will help us guide the development of our user-inspired results. He also committed to providing our team access to a construction site in Houston to collect data for our minimum viable prototype.

Mr. Pedro Ibanez is a successful strategy planner at Bartlett Cocke - General Contractors. He has granted us access to a construction site in San Antonio, Texas, to interview project managers to understand the daily routines of main craftworkers.

IP strategy advisors:

Saurabh Biswas, Ph.D. serves as the executive director for Commercialization and Entrepreneurship at the Texas A&M Engineering Experiment Station. His over 15 years of combined experience in medical technology innovation, health care entrepreneurship, and new ventures portfolio management will be key for our IP strategy from day one.

Mr. Jim O'Connell is the Assistant Vice President of Commercialization and Director of Tech Transfer at the University of Florida. His role will be key for our IP strategy as well as he is responsible for commercializing and translating UF technologies into the marketplace and all startup activity with AI POW LLC.

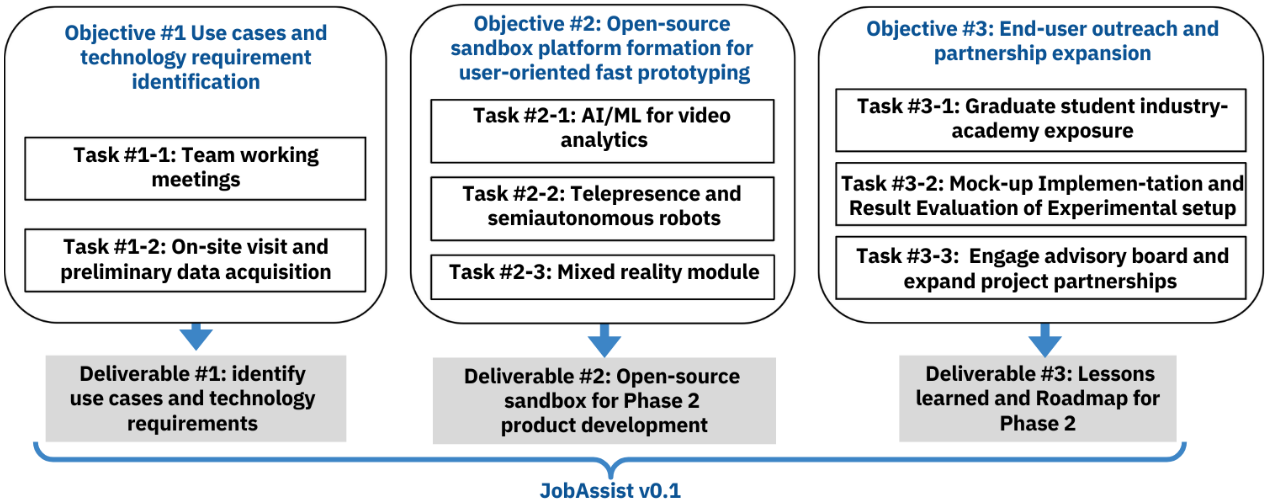

Figure 4: Building Community via a Cohort Model for Participants

4 Building Community via a Cohort Model for Participants

Overview of the Research Tasks. Our Phase 1 goal is to define the work digitization platform for the construction industry using a mixed reality system that accelerates the integration of computer vision, semi-autonomous ground robots, and AR into telework for PWDs. To achieve this goal, we will focus on the following set of objectives. To address the PWD-industry needs mentioned above, in this project, we propose three objectives summarized in Fig. 4. Specifically, In **Objective #1**: we will define use cases industry and technology requirement identification for a holistic understanding of the PWD community, their work, and how our proposed technologies can best enhance the existing construction industry workflows. In **Objective #2**: we propose to develop an open-source sandbox for user-oriented fast prototyping to test and validate/invalidate that our AI/ML, autonomous robots, and mixed reality propositions have value for both PWDs and the construction industry. In **Objective #3**: we plan to reach out to the end-user for further user testing and to define the partnerships required to complement our skill set to produce a solution that users want in phase 2. In the remainder of this section, we present the details of each objective.

4.1 Objective #1: Use cases and technology requirement identification

In this objective we will engage with scientists and stakeholders for information discover, and better user and industry understanding.

Task #1-1: Team work meetings. We will have two workshops and bi-weekly working sessions with our core team from January 2023 to January 2024 to promote collaboration, discuss and address pressing requirements, and draw on experiences. The PI and Co-PIs plan a Kickoff meeting with our assistive technology advisory board in February 2023 and the monthly meeting thereafter. The PI and Co-PI Diane Collins will involve PWDs in these working meetings through focus groups and formal interviews. We will organize separate breakout groups for each discipline and collective brainstorming sessions to shape and influence the convergence effort. To fuel stakeholder thinking on PWD application cases and technological value propositions, industrial partners will deliver software and hardware illustrative of upcoming technology capabilities. To promote research and outreach efforts at the undergraduate and graduate levels, the PIs will conduct special student sessions for oral and poster presentations at Rice University's D2K lab..

Task #1-1: On-site visit and preliminary data acquisition. We propose a three-day study

Figure 5: Low-fidelity End-to-End Mixed Reality System to bridge the gap for Latinx With Mobility Impairments and augmented-on-site work for the Construction Industry. (Left) An initial hypothesis to test if our proposed end-to-end solution will effectively enable automated real-time coaching feedback for cognitively impaired individuals. (Right) Our AutoVideo-based wireframe will present a tentative answer to remote work designed for PWDs with mobility impairments. Our planned iterative wireframes and prototypes will feature a series of incremental steps in complexity by introducing semi-autonomous robots (on-site) and mixed reality (at home) for our test group at the construction site and PWDs at home.

on each of the sites provided by our industry partners to accomplish the following tasks: 1) interviewing project managers to understand the daily routines of main craftworkers (which are predominantly Latinx), the safety protocols in place, the crew size and schedules, construction-related hazards, and the project site layout; 2) examining historical construction logs, and management documents to identify at-risk activities and at-risk locations as the focus of our study; 3) interviewing front-line craftworkers on their concerns related to situational awareness and safety, and 4) collecting the job site spatial data with cameras and reality capture devices such as LiDAR for the minimum value prototype test. With the loss of generality, the two projects will include a commercial project (school) and an industrial project (power plant), as they are usually more complex and dangerous than other construction projects. In addition, we will focus on understanding the experience and requirements of mechanical workers (e.g., pipe fitters) because their tasks rely on collaboration with many other crafts and construction equipment, representing more risks.

Additionally, AI POW LLC and the key academic partners will alternate hosting the team operational meetings so that each partner organization may arrange tours (virtual and in-person) of their research facilities for the attendees of these sessions.

4.2 Objective #2: Open-source sandbox platform formation for fast prototyping.

Our team has developed the highly praised open-source package AutoKeras, the #1 automated deep learning software on GitHub with over 8,600 stars in 1,400 forks. We plan to build upon such experiences and develop a knowledge repository to be a reference for the PWD community and the future of work, but also to share the research tools, data, design requirements, simulations, models, and findings emerging from this project. We envision this will accelerate the development and integration of these technologies in their own right and enable a diverse community of researchers, technology developers, practitioners, and industry to leverage our efforts as more advanced technologies continue into the construction industry and other work domains. We also foresee this effort as enabling us to serve as an educational focal point for training the next generation of augmentation technology developers and users in construction.

Task #2-1: AI/ML for video analytics. As part of this task, we are planning to build upon our previous work AutoKeras [8] and AutoVideo [9], a system for automated video analysis, and generate a low-fidelity prototype as seen in Fig. 5. This early prototype will be open-sourced as the starting point as we endeavor to identify key learning system values, use-cases, and technology requirements to achieve a holistic understanding of the PWD community, their work, and how our proposed technologies can best enhance existing workflows for the construction industry.

Task #2-2: Telepresence and semiautonomous robots. *This task aims to explore an MR-enabled behavioral intervention system to guard the onsite PWD workers (actors) based on knowledge of the offsite PWD worker (guard).* The previous task helps transfer the construction site spatial information to the offsite PWD worker (guard) for site information processing and for providing guidance. It is still needed to convey the guidance information to the onsite worker (actor), including timely warnings or interventions when dangerous behaviors are observed. We again propose to use MR HMD, such as HoloLens, as the user interfaces for behavioral intervention for the onsite PWD workers (actors). We offer to develop a novel bridge protocol for sending real-time guidance information to remote HoloLens via game engines. As shown in Fig. 6, the offsite PWD worker (guard) can select or create virtual objects (e.g., a warning sign) in Unity, while the changes are sent to remote HoloLens systems via an HTTP protocol. Although similar products are available through commercial vendors, such as Microsoft dynamic 365 services, they only provide closed functions that do not work for all construction needs. For example, in one scenario, the offsite PWD worker (guard) may need to mark a warning sign on the point cloud model collected from the LiDAR scanner. In another scenario, the offsite PWD worker (guard) may even control the remote robot to intervene with the onsite worker (actor). These functional needs require direct access from Unity to ROS for alerting point cloud data and instructing the robot. Our proposed system includes two channels different from most existing commercial products. The first channel allows the offsite PWD worker (guard) to send communications directly to the onsite worker (actor), which we call "warning to person." Examples include warning texts and symbols displayed in HMD directly. We will rely on Photon Unity Networking (PUN) for real-time synchronizing data between two AR systems. The second channel enables the offsite PWD worker (guard) to alter the rendered point cloud model and the remote robot via AR interaction, which we call "warning to the environment." The changes will be reflected on the HMD of the onsite worker (actor) when their device subscribes information from ROS sever. To be noted, although the final changes are shown in the same HMD of the onsite worker (actor), the data infrastructure differs from the "warning to person" AR-to-AR communication method. Changes are sent to ROS from the offsite PWD worker (guard) and then broadcast to an onsite PWD workers (actor). This new channel will build on a novel Unity-to-ROS data exchange system developed by Du's team.

Task #2-3: Mixed reality module. *This task aims to design and test a reliable and scalable virtual telepresence system for onsite and offsite workers collaborating in hazard detection and safety assurance based only on sparse sensor data.* Modern construction workplaces are often spatially complex and less controlled. Unexpected moving objects and people, large amounts of activities at the work interface, and changing outdoor environments (light conditions and weather) all require a significant level of situational awareness for safely performing construction tasks. Such a strict re-

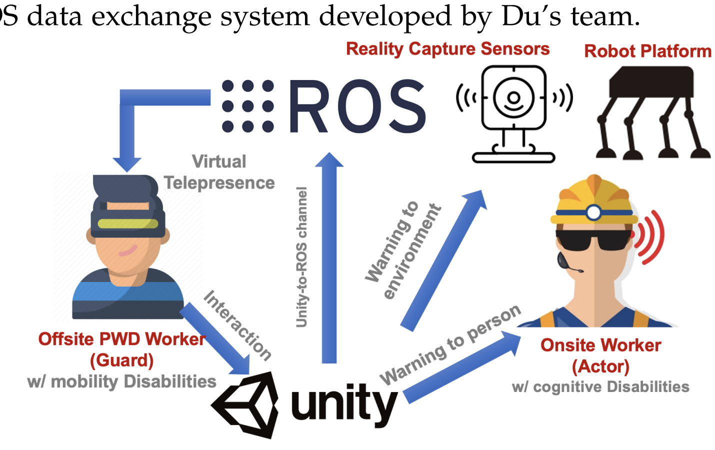

Figure 6: Behavioral intervention based on offsite guard – onsite actor AR interactions.

quirement posts a high barrier for people with certain cognitive disabilities (i.e., Attention-Deficit) or cognitively impaired. To broaden the career opportunities of this special group of population in the construction industry, secondary guidance should be provided to augment their situational awareness and responsiveness. Our proposed solution builds on virtual telepresence technologies to share the construction site information, mainly spatial models, with a functioning person at a distance (i.e., guard), for providing real-time guidance when situational awareness of the on-site worker (i.e., actor) is in question. The solution includes a reality capture system (including sensors and a quadrupedal robot as the mobile platform) to build a high-fidelity construction site model in real-time and render it in a mixed reality head-mounted display (HMD, such as HoloLens) via a game engine. Two ongoing problems with the current approach have impeded the adoption willingness of similar reality capture and modeling technologies. First, because of the amount of spatial data to be processed and transferred, the capture and rendering do not usually happen simultaneously, especially when the application involves long-distance telecommunications. Therefore, real-time collaboration is needed for safety assurance and situational awareness augmentation. Second, the deployment cost of any new technology would be the main concern for construction businesses, given the high competitiveness of the construction industry. As a result, we propose to design and test a novel scene reconstruction method by utilizing only low-resolution LiDAR for high-fidelity 3D model rendering via light AR HMD.

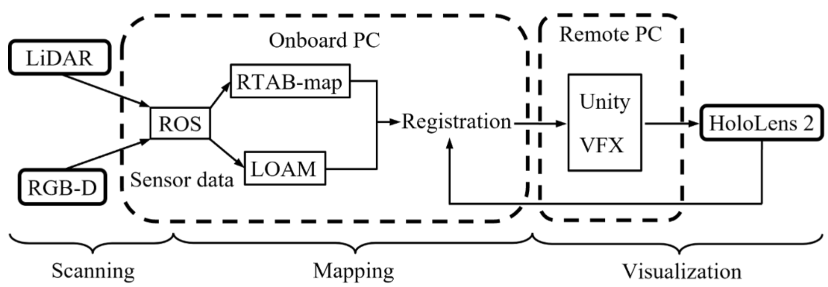

Figure 7: Workflow for virtual telepresence based on reality capture.

Our method uses a low-resolution mobile LiDAR scanner and commercial depth cameras to build a dense 3D reconstruction map for indoor scenes. We propose to use Velodyne VLP-16 LiDAR to collect point cloud, and the method could also be extended and implemented based on the other types of LiDAR sensors. VLP-16 has 30 degrees vertical scanning range from -15^0 to 15^0 with 16 horizontal laser rings. Each ring includes 360-degree scanning points with a rotation speed ranging from 300 RPM (revolutions per minute) to 1200 RPM. The raw point cloud data collected from the LiDAR scanner is considered sparse. On the other hand, the depth cameras can capture high-density raw data, but the range of coverage is much smaller no more than 5 meters. We propose a system that takes advantage of both sensors and uses a novel algorithm to fill the sparse data with synthetic and secondary. Figure 7 illustrates the workflow for integrating raw data from multiple sensors for the real-time reality capture and rendering the model in HoloLens 2 simultaneously. The system will be composed of three major parts: Scanning, Modeling, and Visualization. The system's first part includes ranging sensors like RGB-D and LiDAR to collect raw spatial data from the surrounding environment. Spatial data is then processed and propagated by ROS (robot operating system) and will be ready for the following process. The second part includes reconstructing and detailing captured data into a visually perceivable digital twin model. To produce a model from point cloud data, SLAM applications are used. This process also includes cross-platform point cloud registration, clustering, segmentation, and augmentation to ensure the accessibility of the digital twin. The processed model is then transferred to the Unity game engine for rendering. Specifically, rendering a large-scaled point cloud model in real-time could be challenging; we utilized the VFX function inside Unity to make this process efficient. The last part will be visualization with AR head-mounted displays, in our case, HoloLens 2 from Microsoft. Such optical see-through

HMD could enable visualization of a virtual model on top of the real world, thus helping the user gain better spatial awareness.

For improving the density of the rendered model in HoloLens without using high-end (and expensive) sensors, we propose a data augmentation approach. The overall process includes two major steps: correspondences estimation and multi-map transformation. For a given point cloud PC_t, the points on edges and planar surfaces are selected as feature points, denoted as E_t and Pl_t, respectively. Let PC_t denote the captured point cloud model at time t, given two consecutive point clouds PC_t and PC_{t+1}, the next step is to find the correspondences based on the extracted feature point sets (E_t, Pl_t) and (E_{t+1}, Pl_{t+1}). At time stamp $t+1$, PC_t is projected into the coordinate S_{t+1} and the resulting point cloud is denoted as PC_t' with the projected feature point sets denoted as (E_t', Pl_t'). PC_t', E_t' and Pl_t' are now in the same coordinates with PC_{t+1}, E_{t+1} and Pl_{t+1}. The key problem is to estimate the optimal transformation matrices $\{T_1^0, T_2^0, ..., T_n^0\}$ between each frame and the original frame. Once the transformation matrices $\{T_1^0, T_2^1, ..., T_n^{n-1}\}$ is estimated, we can get $\{T_1^0, T_2^0, ..., T_n^0\}$ to reproject frame 1 to frame n back to frame 0. The selected VLP-16 only has 16 rings to cover a vertical angle range from -15^0 to 15^0. Thus, there will be huge gaps between vertical rings, which is the main reason for data sparsity. To tackle the problem and build a dense indoor reconstruction map, we slightly rotate the LiDAR sensor around the x and y axes by β in both clockwise and counter-clockwise directions, as shown in Fig. 8. This is done by controlling the locomotion of the quadrupedal robot in a corresponding way. The scanning results from different views with different β values are projected back to the initial frame with $\beta = 0$. Let β_t denotes the horizontally rotated angle at timestamp t, then the final reconstructed map is $PC_{all} = \{T_1^0 \cdot PC_1, T_2^0 \cdot PC_2, ..., T_t^0 \cdot PC_t, ..., T_n^0 \cdot PC_n\}$. The final reconstructed map PC_{all} will be down sampled and sent to Unity through ROS sharp. Therefore, the vertical resolution could be largely improved. We programmed a unique locomotion pattern for the robot as it moves a certain angle vertically for filling the sparse LiDAR data. It will be discussed in detail in the following sections.

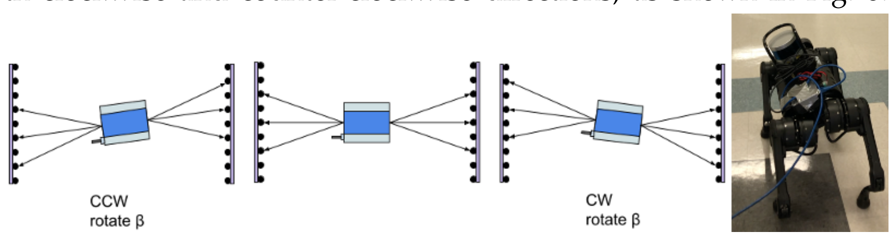

Figure 8: Rotation of the sensor in both CCW and CW direction enable the rings to cover the gaps of rings from the initial frame.

4.3 Objective #3: End-user outreach and partnership expansion.

For this objective, our team has planned an industry-academy development plan for the students involved to help perform field studies to gain a deeper understanding of the construction site activities and collect data for the minimum viable prototype test with PWDs from the construction industry (predominantly Latinx in both sites in Texas). In addition, the PI will inform the assistive technology advisory board regularly regarding our on-site progress and to assess the need for new partnerships needed as we move forward to a full implementation for Phase 2.

Task #3-1: Graduate student industry-academy exposure. Our team has made a cross-disciplinary mentoring plan to help the student succeed in academics and entrepreneurship. The mentoring plan will enhance the knowledge and readiness of the student for innovation and technology commercialization beyond the usual research experience. It consists of three components: (1) the Ph.D. student will be guided by both PI and Co-PI to understand the process behind a user-centered product design. (2) The team has planned to offer the student participate in a cross-disciplinary internship at AIPow. The student will engage with the R&D department in charge of co-developing CV technologies, as well as with the AIPow's management team, in charge of developing the company's market strategy and directly responsible for translating research outputs into products. The planned internships aim to expose students to the full product development process and help them visualize how customer needs are translated into technology developments and final product specifications. (3) We will work with Rice's Lilie Center for Entrepreneurship to help the student understand how to transition the research into a commercial product. One particular program we plan to participate in is the OwlSpark Accelerator, a multidisciplinary program that helps students explore a core company hypothesis to decide to accelerate, pivot, or rightfully shut down their venture. This program includes workshop sessions, where veteran entrepreneurs lead workshop sessions and provide their knowledge on building a business.

Task #3-2: Mock-up Implementation and Result Evaluation of Experimental setup. As part of our pains and gains discovery process, we will implement a series of mock-ups that can make tangible our vision for PWDs and the future of work. Such designs are built form of wire-frames, off-the-shelf VR headsets, commercial cameras, and inexpensive 3D printed models. We aim to interact with the end user and test the initial hypothesis to validate or invalidate them.

To better understand the activities taking place on the building site and gather information from our first minimum viable prototype, our team will return to the construction sites visited in task #1-1 and conduct two pilot field investigations to validate or invalidate different features included in the prototype AutoVideo v0.1. This set of interviews (in Spanish and English) are planned to reach out to people working in construction that report a cognitive or mobility impairment. The research locations will be two building projects in San Antonito and Houston, Texas. We recommend conducting a three-day study to validate the following activities on each site. On day 1, we will speak with project management to validate AutoVideo's features to help with Latinx craftworkers' daily routines, safety procedures in place, crew size and scheduling, and risk prevention associated with construction. On day two, we will test our risky-activity recognition ML model trained on previous construction logs, risk registration forms, and management records to pinpoint at-risk activities and at-risk regions. On day three, we will validate with front-line craft workers our possible solutions to enhance their safety and situational awareness worries.

Throughout Phase 1 and, more importantly, through Phase 2, we want to pair scientific R&D on CV, VR, and robotics and a build-measure-learn feedback loop to provide corresponding engineering solutions in our platform to address the problems above. Specifically, we will expand our findings into our system by following our previous mock-up testing following a lean methodology approach. In addition, we expect to use such lessons in Phase 2 to advance the end-to-end AutoVideo system by building upon the most requested features from the interviews conducted during our customer discovery process.

Task #3-2: Engage advisory board and expand project partnerships The planned advisory board's engagements include: (1) Identify product-market fit difficulties, and exchange information and expertise (2) Help address issues that need to be resolved before Phase 2 begins regarding non-disclosure and intellectual property agreements. (3) Be the point of contact to get in touch with pertinent researchers, labs, practitioners, and educators to find more Phase 2 participants and disseminate information (4) Synthesize talks from workshops into a "convergence knowledge repository" for directing future project reference and dissemination.

A core team of academic and business partners has been established, along with an initial advisory board of PWD-focused practitioners and non-profit organizations. These groups' main goal is to provide strategic advice and their knowledgeable perspectives on assistive technology, the workplace, and work situations in order. Finally, if extra demands for a particular area of study or development arise, the project team will recruit new members as necessary, depending on feedback from the core and advisory teams.

5 Building an Inclusive and Diverse STEM Workforce

Overall, customer discovery will take nine months with another three months of follow-up activities from NSF. Milestones and deliverables are shown in the table below.

PROJECT TIMELINE start January 18, 2023 - end January 17, 2024			Months								
Research Objectives	**Tasks**	**Team**	M1	M2	M3	M4	M5	M6	M7	M8	M9
Milestones					D1			D2			D3
O1: Use cases and technology requirement identification	Kickoff meeting	AIPow, UTMB, UF, Rice, TAMU									
	Team working meetings	AIPow, UTMB, UF, Rice, TAMU									
	On-site visit and preliminary data acquisition	AIPow, UF									
O2: Open-sourced sandbox platform for prototyping	AI/ML for video analytics	AIPow, Rice									
	Telepresence and semiautonomous robots	UF, TAMU									
	Mixed reality module	AIPow, UF									
O3: End-user outreach and partnership expansion	Graduate student industry-academy exposure	AIPow, Rice									
	Mock-up Implementation and Result Evaluation of Experimental setup	AIPow, UTMB									
	Engage advisory board and expand project partnerships	AIPow, UF, UTMB									
Continous innovation	Action Items from User Testing Results to Iterate development	AIPow									
	Team bi-weely meetings	AIPow, UTMB, UF, Rice, TAMU									
	Bi-monthly peer-project FULL TRACK H meetings	AIPow									

AIPow: AIPow LLC team led by PI Alfredo Costilla-Reyes
UTMB: University of Texas Medical Branch led by Co-PI Diane Collins
UF: University of Florida team led by Co-PI. Eric Jing Du
TAMU: Texas A&M team led by Co-PI. Frank Shipman
Rice: Rice University team led by Senior personnel. Xia 'Ben' Hu

D1 **Identify use-cases and technology requirements**
D2 **Open-source sandbox for Phase 2 product**
D3 **Lessons learned and Roadmap for Phase 2**

Notation:
D# **Deliverable**
O# **Objective**

Figure 9: Proposed project timeline.

Deliverable #1: Identify use-cases and technology requirements. This report will include our preliminary research and key takeaways from interviews with the PWD community, their work, and how our proposed technologies can best enhance existing workflows.

Deliverable #2: Open-source sandbox for Phase 2 product development. This open source knowledge sharing platform will accelerate advances in and integration of assistive technologies into work contexts for the construction industry.

Deliverable #3: Lessons learned and Roadmap for Phase 2. The team will create a comprehensive plan that contains a breakdown of Phase 2 deliverables into specific components, tasks, services, and performers, as well as critical dependencies and unknowns that must be resolved. This plan will be continually updated during Phase 1, to ensure that our team is ready to embark on a competitive Phase 2 effort by the beginning of 2024.

Fig. 2 show our goals for Phase 1, 2, and growth phase. Our phase 2 deliverables by the end of 2024 involve building a larger cross-disciplinary team with more scientists and stakeholders who can contribute to creating the newer AutoVideo version 1.0, a fully functional software + hardware product for more complex decision scenarios and incorporating these software tools into scalable telework available for PWDs in the construction industry. In Phase 2, we propose to build a third 'Agile design' loop in Fig. 2 (right), which is a highly collaborative way to design and develop new products that are advancing from the lean methodology design; agile design transform big tasks into groups of subtasks to be performed in short sprints. By March 2026, our team would have de-risked the AutoVideo technology and will have approached external funding (angel investors and venture capital) to support its commercial expansion.

6 Sustainability and Scalability

Accelerating Disability Inclusion in Workplaces Through Technology, an NSF-sponsored workshop held in May 2021, emphasized the need for more tightly integrated partnerships to support the creation of new social and economic-based initiatives to improve employment, hiring, and workplaces for people with disabilities. The involvement of many stakeholders will be necessary for hiring and workplace accommodations. Our team plans to rapidly develop assistive technology and tools that will enable a population that has previously lacked such treatments to join the workforce for the greater good of society. As technology advances, new stakeholders will be invited to work cooperatively to add their expertise as we build AutoVideo and the future of work for PWDs and the construction industry.

In this work, the stakeholders involved include partnerships between the following: PWDs, industry, researchers, advocacy groups, non-profits, non-governmental organizations, communities, educational organizations (undergraduate and graduate, postdoctoral), faculty, and practitioners (e.g., occupational therapists). Our joint work will lead to the following tangible outcomes: (1) Tools and technologies for recruiting PWDs (e.g., incorporation of strength-based metrics, diversity, equity and inclusion initiatives that include disability), (2) Methods for enhancing community building and employment networks for people with impairments, (3) Calculate the economic impact of raising the employment rate of PWDs in the US.

The workshop determined a toolbox for telework as one of the most crucial applications for this track H. Our work also stresses the importance of user interviews to get this right, because while we believe that teleworking helps with certain mobility issues, we are also aware that telework may present a different difficulty that is significant for PWDs as this technology also introduces new difficulties. For example, people with poor dexterity have trouble entering data into computers. Therefore, to better align our solution with this Track H, we have designed our fast-prototyping AutoVideo platform to be very flexible and allow for pivots if these are supported with data from interviews and user-testing. It is important to notice that we are also designing AutoVideo to be reliable and secure while respecting users' privacy.

In addition, our team has planned bi-monthly meetings with all the funded projects in this track H to provide a venue to exchange findings among peers and hear their feedback. The challenges faced for the future of work for PWD are very complex and would require leadership from our end to share resources as if we were just one team in this track H. Therefore, we plan to open our deliverables and open-source platform to other funded teams of this track H. **In addition, we see this convergence accelerator as a unique opportunity to reach out to other talented experts; therefore, we will invite track H peer participants to serve as our advisors, take a leadership role, and fully collaborate with us in Phase 2 of this program and beyond.**

7 Evaluation

8 Generation of Knowledge

9 Broader Impacts

This project's results will have an immediate and substantial social impact on improving the job opportunities for PWDs. The proposed open-source sandbox for fast-prototyping will allow the team to understand PWDs needs to better design telework tools to enable on-site jobs in the construction industry that were previously not available to PWDs. The assistive technologies developed in Phase 2 will have an immediate impact on a population that urgently needs to be part of the workforce for the greater benefit of society.

At the same time, the proposed project well aligns with two of NSF's 10 Big Ideas [10] to positively impact our community and society: **(1) Future of Work at the Human-Technology Frontier -** by increasing the adoption of the proposed advanced technologies, more companies can adopt complex AI, robotics and mixed reality technologies. Successful human-technology partnerships could effectively enhance human performance to simplify excessive amounts of data into actionable items to boost construction safety, and quality assurance. **(2) Harnessing the Data Revolution -** this project aims to design easy-to-use tools tailored to the construction industry. **This reduction in complexity and deployment cost can accelerate the technology adoption for a larger group of businesses that can now embrace the data revolution.**

9.1 Broadening Participation Plan

The challenges faced by the disabled population in contributing equally to our society has implications for our economies and human rights, equality, equity, and diversity. Our broadening Participation Plan includes:

University education and K-12 outreach: Undergraduates and graduate students will be recruited during our two planned workshops of Phase 1 to participate in stakeholders engagement activities, data processing, and software development. In addition, Dr. Hu and Dr. Costilla will continuously promote among K-12 students the interest in developing assistive technologies at the D2K lab at Rice University.

Recruiting women and URM students: Dr. Costilla is currently mentoring two female high school students through a summer internship program in partnership with Rice University, Dr. Hu will expand these efforts by doubling the participation of female students in Phase 1 of this program. Also, Spanish-speaking student ambassadors will be invited to collaborate on our prototype development and expand language support for the Latinx community.

While we currently have PWD in central and peripheral roles in this proposal, we have partnered with the organization Knowbility, Inc, an accessible information technology nonprofit organization based in Austin, to help us increase the number of PWDs in leadership roles by increasing our recruiting efforts to attract more investigators self-identified as PWD.

10 Results from prior NSF and outside support

Costilla Reyes, Alfredo. PI. NSF SBIR (2136679) $255,889.00; 02/22 - 10/22 Phase I: *A Hardware-Aware AutoML Platform for Resource-Constrained Devices*. Intellectual merit: this project is a flexible and modular hardware-aware machine learning model generation system that reduces manual efforts by automatically generating complex machine learning models for resource-constrained devices. The goal of AutoEdge is to produce a prototype that a domain expert with basic programming knowledge can use to create advanced AIoT with no computer science background. Broader Impacts: the proposed project's successful outcome will enable the fast, affordable, and easy creation of on-device AI with significant industrial applications. Publications: [9,11].
Du, Eric Jing PI, FW-HTF 2128895, $1,457,425, FW-HTF-R/Collaborative Research: Human-Robot Sensory Transfer for Worker Productivity, Training, and Quality of Life in Remote Undersea Inspection and Construction Tasks Intellectual merit: VR-based telepresence technology for underwater robot controls. It also includes new educational materials for workforce transformation and the corresponding economic impact analysis. Broader Impacts: VR for lowering robotic technology adoption; promoting career equity in the maritime industry.
Shipman, Frank IIS 18-16923, $499K, 08/18-07/23, "CHS: Small: Non-Programmer Authoring of Data-Driven Prediction Simulations". Intellectual merit: This project aims to understand how teachers view the increasing availability of data in their domains, the available tools, curricular activities, and the overhead of creating and tailoring activities to their environment. Broader Impacts: This project explores ways to support educators as they introduce interactive data-driven activities to help learners develop intuitions about data and acquire specific analytic skills. Publications: [12].

Hu, Xia (Ben) Xia Hu PI. Project: IIS-1939716, $509,211, 3/2020 - 2/2023. Title: FAI: "Towards Fairness in Deep Neural Networks with Learning Interpretation." Intellectual Merit: This project systematically investigates and facilitates fairness in deep neural networks by leveraging the interpretability of key elements in a machine learning life-cycle, including modeling, data preparation, and feature engineering. Broader Impacts: This project includes training of four graduate students, including one female student and two undergraduate students. Publications: [13–15].

11 Budget

12 Facilities, Equipment and Other Resources

13 Data Management Plan

14 Mentoring plan

15 Letters of collaboration

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