DESIGNING AN AUGMENTED REALITY BASED INTERFACE FOR WEARABLE EXOSKELETONS

Chaitanya Kulkarni, Hsiang-Wen Hsing, Dina Kandi, Shriya Kommaraju, Nathan Lau, & Divya Srinivasan
Grado Department of Industrial and Systems Engineering
Virginia Tech

Full-body, powered wearable exoskeletons combine the capabilities of machines and humans to maximize productivity. Powered exoskeletons can ease industrial workers in manipulating heavy loads in a manner that is difficult to automate. However, introduction of exoskeletons may result in unexpected work hazards, due to the mismatch between user-intended and executed actions thereby creating difficulties in sensing the physical operational envelope, need for increased clearance, and maneuverability limitations. To control such hazards, this paper presents a rearview human localization augmented reality (AR) platform to enhance spatial awareness of people behind the exoskeleton users. This platform leverages a computer vision algorithm called Monocular 3D Pedestrian Localization and Uncertainty Estimation (MonoLoco) for identifying humans and estimating their distance from a video camera feed and off-the-shelf AR goggles for visualizing the surrounding. Augmenting rear view awareness of humans can help exoskeleton users to avoid accidental collisions that can lead to severe injuries.

BACKGROUND

Wearable exoskeletons are rigid machines capable of providing high level of support and assistance to targeted joints, with a goal of reducing physical demands and overall metabolic cost to the human body while performing strenuous tasks (Sawicki, Beck, Kang, & Young, 2020). Several exoskeletons that focus on strength augmentation of specific joints have been previously developed. The Berkeley Lower Extremity EXoskeleton (BLEEX) was designed to enhance load-carrying capacity of a human through strength augmentation of torso and legs (Kazerooni, Chu, Steger, & Steger, 2007). Similar kinds of exoskeletons that operate on lower extremity are the Hybrid Assistive Limb (HAL), the Roboknee, and MIT Exoskeleton as reviewed by Ansari, Atkeson, Choset, & Travers (2015). As many tasks, such as material handling, require actuation and forces on many human joints (Marcheschi, Salsedo, Fontana, & Bergamasco, 2011), full body exoskeletons are also being developed such as the 'Body Extender' by PERCRO Laboratory (Marcheschi et al., 2011) and the Guardian XO™ by SARCOS Robotics. ("Sarcos Robotics - Global Leader in Robotic Technology & Solutions," n.d.).

With recent advances in technologies that provide effective sensing capabilities, energy storage, and mobile computing, wearable and powered exoskeletons are ever closer for deployment to aid operators in labour intensive tasks such as manufacturing where precision and strength are essential (Dahmen & Constantinescu, 2020). The reduction of physical demand on the body can reduce job-related injuries. Along with lowering risks of injuries in work-places, exoskeletons can improve equal job opportunities for vulnerable populations by allowing them to enter and stay employed in physically demanding jobs that are otherwise inaccessible. The potential implications of exoskeletons on the workforce could be transformative for a wide range of industries.

Although considerable research in technology development and proclaimed benefits in strength augmentation is on-going, limited attention has been devoted to resolving problems that could arise during industrial operations. Fox, Aranko, Heilala, & Vahala (2019) reviewed exoskeleton technology identifying a long list of challenges in deploying exoskeletons in manufacturing settings. One problem is the variability of operations and workers that resulted in unexpected loading on human users negating benefits revealed in some controlled laboratory settings (Picchiotti, Weston, Knapik, Dufour, & Marras, 2019). Further, physically augmenting humans through wearable exoskeletons and safely controlling the augmentation technology can place new and unique cognitive demands on the human user when operating in and navigating through industrial environments (Fox et al., 2019). In particular, wearing exoskeletons may inevitably interfere with our innate motor-control abilities that in turn imposes additional cognitive demand on the exoskeleton users. The additional cognitive demands associated with operating such augmentation technology may be so high that may result in displacing rather than supporting some working population groups. While some of these may be combated by more intuitive designs of exoskeleton hardware and controls and through user-training, not all user groups may be trainable to the same extent and such additional attentional and cognitive demands may create critical safety hazards in industrial environments.

Increased cognitive workload may present challenges for maintaining appropriate situation awareness (SA; Endsley, 1995; Lau & Boring, 2017) of the surrounding, potentially leading to unintentionally colliding with near-by objects, humans or other exoskeletons in dynamic work environments. Such mechanical hazards have been observed with other powered equipment such as forklift accidents, especially when drivers were engaged in complex or secondary tasks (Choi, Ahn, & Seo, 2020). Similar scenarios can be anticipated in the case of an exoskeleton user who may injure others due to lack of spatial awareness as head movement for visual survey of the surrounding becomes restrictive and proprioception of body movement is hindered. An exoskeleton coming into contact with people or objects behind the user seems particularly likely in various industrial settings where spaces may be tight, people or machines may be moving in the vicinity, potentially causing fatal accidents.

Computer vision (CV) supported by sensors attached to the exoskeleton is prime to help users become more aware of their surroundings. For example, camera based sensors employing CV for obstacle detection has been demonstrated for automated parking of road vehicles at a relatively low cost (Heimberger, Horgan, Hughes, McDonald, & Yogamani, 2017). This paper presents a prototype platform that employs the Monocular 3D Pedestrian Localization and Uncertainty Estimation (MonoLoco) CV algorithm and augmented reality (AR) goggles to enhance the rearview spatial awareness of exoskeleton users.

The remainder of the paper is organized as follows. The next section describes the implementation of MonoLoco and AR display to detect and visualize human beings at the rear of the exoskeleton users. Then, the paper discusses the applications and challenges in deploying the prototype. The paper concludes with a proposed demonstration of the rearview human localization AR platform for the 2021 HFES Annual Meeting.

REARVIEW HUMAN LOCALIZATION AUGMENTED REALITY PLATFORM

Our rearview human localization AR platform comprises of the Magic Leap AR goggles and two standard USB video cameras of a 90^{o} viewing angle connected to a Virtual Reality (VR) ready portable backpack computer. Figure 1 presents the physical set up of the hardware

The VR backpack computer runs MonoLoco to process a video feed from one of the USB camera to identify humans and estimate their distances. The computer also hosts the Unity game engine and the Magic Leap SDK for creating the visualization of the humans located behind an exoskeleton user for display on the Magic Leap goggles.

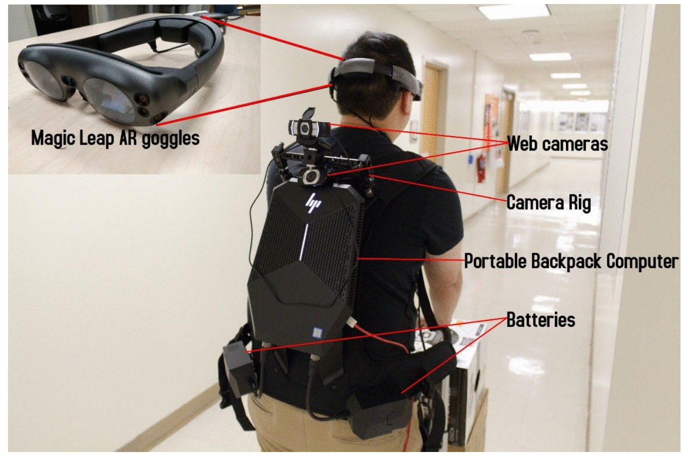

Figure 1: Rear-viewer human localization AR platform

Human Detection by MonoLoco

Bertoni, Kreiss, & Alahi (2019) developed MonoLoco, a new architecture of several neural networks (NN) that enables low-cost real time 3-dimensional localization of pedestrians with a live video stream for autonomous vehicles. MonoLoco utilizes a two-step process. The first step involves running a top-down Mask R-Convolution NN and a pose detector-Pif-Paf that represent identified humans in an image in terms of their joints in 2-dimensional form with estimates for the depth of the pixels depicting the humans. The second step employs a feed forward NN to process the depth estimation provided by the pose detector for computing distance of the detected humans from the camera with consideration of uncertainty.

As discussed earlier, exoskeleton users can benefit from knowing humans at the rear to prevent accidents. Thus, we employ MonoLoco to process a video feed to locate humans behind the exoskeleton user. For the purpose of testing, we run MonoLoco on a portable VR ready backpack computer mounted with a USB camera (as opposed to full exoskeleton implementation). MonoLoco provides the localization data in terms of distance of detected humans relative to the camera. A UDP server is developed to send the localization data to Unity which is used to visualize the locations of the detected humans. Another camera is set up to provide Unity with a rear-view video stream.

Visualization of Localized Humans

The localization data of the humans detected by MonoLoco is visualized with a radar graphic in Unity (Figure 2). The radar visualization under development currently has two rings depicting 1.5 and 3 meters away from the user/camera, respectively. The two rings are intended to define hazard zones in which sudden movements could result in accidents but the optimal values are still subjects of research. The arrow indicates the direction the user is facing while the diagonal lines mark the 90 degree viewing angle of the USB camera, the region in which humans can be located. A red dot depicts a human being located by the MonoLoco inside the hazard zones (i.e., closer than four meters). Furthermore, a rearview video window appears on the top-right whenever MonoLoco detects a person inside the hazard zones. This live video feed is provided by another web camera mounted on the computer. All visualizations are displayed to the user through the Magic Leap AR goggles as exemplified in Figure 3, which corresponds to the scene in Figure 4.

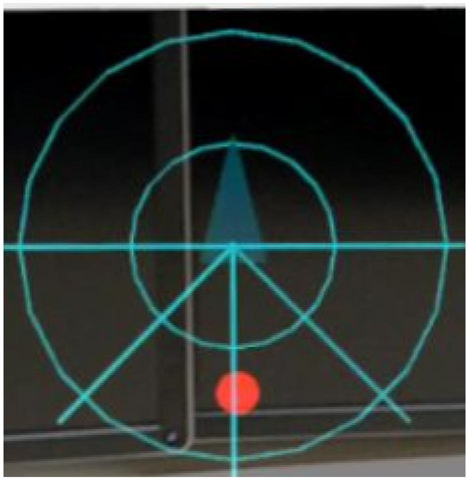

Figure 2: Radar Plot as seen through AR goggles

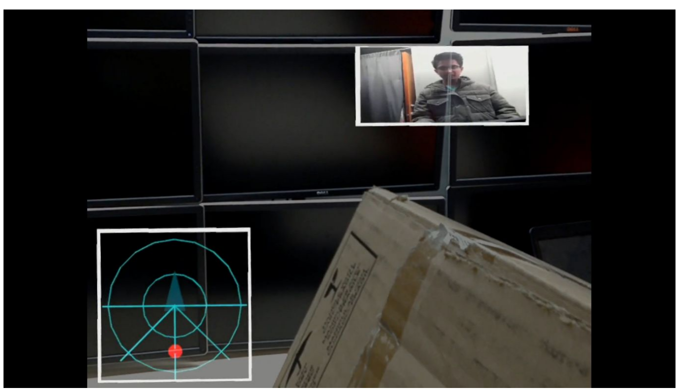

Figure 3: Visualization through AR goggles

DISCUSSION AND CONCLUSION

Our rearview human localization AR platform aims to prevent injuries from accidental collisions with exoskeleton users by augmenting perception of humans at the rear. This increased spatial awareness of the surroundings can be beneficial on the job floor wherein exoskeletons deployed for day-day tasks may be prone to accidents because of hindered proprioception and visual perception while physical strengths are augmented.

Figure 4: Simulating a task of lifting a box.

Substantial research is necessary to address the cognitive challenges in deploying the rearview human localization AR platform for exoskeleton users in operational settings. One challenge is determining optimal visualization design that maximizes user spatial awareness. The design issues include parameters defining the hazard zone, size and viewing angles of the video feed, and location of the visualizations. Moreover, the visual cues that help users in gauging the distance of the humans behind them should be explored. The aforementioned research investigations are necessary to balance availability and overload of visual information, especially when the work is already visually demanding and/or situated in a condense environment. That is, the use of the rearview AR platform may introduce unwarranted distractions and interruptions, and further research is necessary to understand the limit on visual perception and the impact of the cognitive load on the user. For this reason, the benefits of other modalities in delivering the necessary spatial information should also be investigated.

Besides avoiding to be a source of mechanical hazards, the exoskeleton user might also need help in augmenting their awareness of dangerous objects in their surroundings due to hindered head movements. Hence, future work should expand the computer vision capabilities to detect such dangers and advance the visualization to inform the users. Lastly, the performance of the system needs to be assessed in different industrial settings.

The MonoLoco algorithm also has several limitations for exoskeleton applications in the operational environment. First, current implementation only processes video feed at 3 frames per second that should ideally be faster for real time operations. Second, MonoLoco is currently optimized for pedestrian identification in the driverless car domain. Thus, the distance estimation error may be higher than desirable due to dynamic uncertainty introduced by the cameras with different field of views and orientation. Further, MonoLoco did not account for variance in human heights for all ethnicities, potentially leading to differential injury rates across population groups. Finally, CV research can advance

MonoLoco by fusing other sensor data to provide more robust and accurate localization of humans in the vicinity.

DEMONSTRATION

A demonstration of the human localization AR platform is proposed for the 2020 HFES Annual Meeting. The demonstration will allow the conference attendees to experience the integrated application of CV and AR technology to enhance spatial awareness of industrial workers thereby preventing accidents and injuries. In this demonstration, the conference attendees will first wear the VR-ready portable computer and the Magic Leap AR goggles. Then, the conference attendees will get to move around and get comfortable with the equipment. Afterwards, the presenters will move behind the conference attendees to trigger the visualization of the localized humans to appear on the Magic Leap goggles. Finally, the conference attendees will be asked to pick up and move large empty boxes while detecting nearby presenters who could be prone to collision. The conference attendees should be able to observe red dots on the radar visualization whenever humans are present behind them, signaling potential hazards and injury-prone scenarios. Further, the attendees should also be able to observe the rearview video feed that provide details of the surrounding behind them whenever humans are detected.

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REFERENCES

Ansari, A., Atkeson, C. G., Choset, H., & Travers, M. (2015). A Survey of Current Exoskeletons and Their Control Architectures and Algorithms, 1–42. Retrieved from www.cs.cmu.edu/~cga/exo/survey.pdf

Bertoni, L., Kreiss, S., & Alahi, A. (2019). MonoLoco: Monocular 3D Pedestrian Localization and Uncertainty Estimation. Retrieved from http://arxiv.org/abs/1906.06059

Choi, M., Ahn, S., & Seo, J. O. (2020). VR-Based investigation of forklift operator situation awareness for preventing collision accidents. *Accident Analysis and Prevention*, *136*(January), 105404. https://doi.org/10.1016/j.aap.2019.105404

Dahmen, C., & Constantinescu, C. (2020). Methodology of Employing Exoskeleton Technology in Manufacturing by Considering Time-Related and Ergonomics Influences, 1–13. https://doi.org/10.3390/app10051591

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1), 32-64. https://doi.org/10.1518%2F001872095779049543

Fox, S., Aranko, O., Heilala, J., & Vahala, P. (2019). Exoskeletons: Comprehensive, comparative and critical analyses of their potential to improve manufacturing performance. *Journal of Manufacturing Technology Management*. https://doi.org/10.1108/JMTM-01-2019-0023

Heimberger, M., Horgan, J., Hughes, C., McDonald, J., & Yogamani, S. (2017). Computer vision in automated parking systems: Design, implementation and challenges. *Image and Vision Computing*, *68*, 88–101. https://doi.org/10.1016/j.imavis.2017.07.002

Kazerooni, H., Chu, A., Steger, R., & Steger, R. (2007). The International Journal of. https://doi.org/10.1177/0278364907074472

Lau, N., & Boring, R. (2017). Situation awareness in sociotechnical systems. In H. M. Cuevas, J. Velázquez, & A. R. Dattel (Eds.), Human Factors in Practice (pp. 55-70). Boca Raton, FL, USA: CRC Press.

Marcheschi, S., Salsedo, F., Fontana, M., & Bergamasco, M. (2011). Body Extender : whole body exoskeleton for human power augmentation.

Martinez, J., Hossain, R., Romero, J., & Little, J. J. (2017). A Simple Yet Effective Baseline for 3d Human Pose Estimation. *Proceedings of the IEEE International Conference on Computer Vision*, *2017-October*, 2659–2668. https://doi.org/10.1109/ICCV.2017.288

Picchiotti, M. T., Weston, E. B., Knapik, G. G., Dufour, J. S., & Marras, W. S. (2019). Impact of two postural assist exoskeletons on biomechanical loading of the lumbar spine. *Applied Ergonomics*, *75*(June 2018), 1–7. https://doi.org/10.1016/j.apergo.2018.09.006

Sarcos Robotics - Global Leader in Robotic Technology & Solutions. (n.d.). Retrieved March 3, 2020, from https://www.sarcos.com/

Sawicki, G. S., Beck, O. N., Kang, I., & Young, A. J. (2020). The exoskeleton expansion: improving walking and running economy. *Journal of NeuroEngineering and Rehabilitation*, *17*(1), 25. https://doi.org/10.1186/s12984-020-00663-9