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A systematic review of computer vision technology applied for individuals with disabilities

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Abstract

This study delves into how computer vision technology is used in the field of disabilities. It examines the potential applications and limitations of computer vision in disability research to analyze the development of computer vision technology, and its technical applications for individuals with disabilities. The study focuses on the positive impact of such technology on the lives of people with disabilities by offering detailed examples of how computer vision technology is practically applied to individuals with various types of disabilities including visual impairment, hearing impairment, and Autism Spectrum Disorder (ASD). It provides insights into innovative changes brought about by computer vision technology in the disability field over the past five years, and offers perspectives on potential development possibilities and future research directions. The comprehensive examination of these multifaceted aspects in this study contributes to a nuanced understanding of the evolving landscape of computer vision technology in the context of disabilities.

Keyword : Computer Vision Technology, Assistive Technology for Individuals Disabilities, Disability Research, Machine Learning, Image Analysis

1. Introduction

Computer vision is the technology that allows computers to process visual data such as images or videos while extracting and interpreting meaningful patterns of information. Computer vision primarily utilizes technologies like deep learning and Convolutional Neural Networks (CNN), enabling essential functions such as optical character recognition, image recognition, pattern recognition, facial recognition, and object detection and classification [1]. Advances in artificial intelligence and machine learning have brought about significant improvements in the field of computer vision. This is largely due to the effective training of deep learning models based on datasets like ImageNet, released in the 2010s, and

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advanced data collection and processing technologies [2]. Furthermore, the advent of smartphones and the subsequent accumulation of high-quality data from various environments have also contributed to the acceleration of deep learning development. Advanced computer vision technology is now being used in various industrial fields including autonomous driving, robotics, security, education, manufacturing, agriculture, entertainment, and health-care [3]. Computer vision technology is crucial in research aimed at individuals with disabilities. While the extent may vary depending on the type of disability, most individuals with disabilities require support for social participation due to mental or physical limitations. Traditionally, family members, professionals, and caregivers have often provided such support. However, with recent technological advancements, numerous studies are being conducted to replace or augment everyday support for individuals with disabilities with technology. The trend of disability-related research utilizing computer vision technology is on the rise. The previous research aimed at improving the quality of life and increasing social participation for individuals with disabilities through computer vision technology can be categorized into three main areas as shown in [Fig. 1].

First, there are studies that use computer vision technology to accurately diagnose specific disabilities by identifying their characteristics. Much of this research focuses on Autism Spectrum Disorder (ASD), where previous studies have analyzed the eye movements and behaviors of individuals with ASD to understand disability-related characteristics [4], and used related data for early screening and diagnosis [5].

Second, research is being conducted to develop various assistive technology devices and systems to support the daily lives of individuals with disabilities using computer vision technology. Assistive technology devices are devices or technologies that help individuals with disabilities perform activities in everyday life more independently. They can support various types of disabilities, such as visual, hearing, and motor impairments [6][7]. For example, wearable devices equipped with object recognition and character recognition functions using computer vision technology have been researched to support the independent mobility and daily life of visually impaired people [8]. These technologies can instantly analyze objects, scenes, and texts in images, empowering individuals with disabilities to navigate different environments more independently [9].

Third, studies use computer vision technology to educate individuals with disabilities or enhance their social interactions and communication. For individuals with hearing impairments who use sign language, communication with non-disabled people who do not use sign language can be challenging. In response, previous research has developed systems that recognize sign language and convert it into spoken language and technologies that convert spoken language into sign language in order to enhance the social interactions and communication of individuals with hearing impairments [10][11].

[Fig. 1] Different Types of Assistive Technologies Utilizing Computer Vision and Machine Learning

The application of computer vision technology in disability-related research presents significant potential for improving the quality of life of individuals with disabilities, along with technological innovation. A systematic literature analysis of the latest research is significant in understanding the trends in the development of computer vision technology and gaining insights into how it can be applied to meet the diverse needs of individuals with disabilities. While there are related prior studies, most investigate research from the late 2000s to the late 2010s, which may limit the reflection of advancements in computer vision technology in recent years. Additionally, each study's scope and target are often limited to specific disability areas, leading to a lack of discussion on various types of disabilities [12].

Hence, this study undertook a systematic review of research articles published between 2019 and 2023 concerning the application of computer vision technology in aiding individuals with disabilities. The primary purpose of this study is to assess its impact on enhancing their quality of life. The study endeavors to provide concrete evidence demonstrating the potential of computer vision technology in enhancing the lives of individuals with disabilities. It will expect to establish a pivotal groundwork for future technological advancements and strategies geared toward supporting this demographic.

2. Methods

2.1 Data collection

This study conducted a systematic search of online databases including Web of Science, Google Scholar, Research Information Sharing Service (RISS), and Korean Studies Information Service System (KISS) to identify the current status of computer vision technology used to improve the quality of life for individuals with disabilities. It focused on publications from the past five years, from 2019 to

November 2023. The search terms utilized were ‘computer vision’, ‘visual computing’, ‘object recognition’, ‘disability’, ‘children with disabilities’, and ‘individuals with disabilities’. The abstracts of the resulting articles were examined to identify relevant studies, and references were also reviewed to find additional articles. To uphold the study's quality, this paper implemented specific criteria to curate the final list of included articles. (1) Only peer-reviewed articles were considered, (2) papers published on non-academic web pages, personal blogs, or patents were excluded, and (3) articles published in both English and Korean were included to conduct a more inclusive analysis. A total of 23 studies were included in this analysis in according with the inclusion criteria.

2.2 Coding procedure

This study aims to examine the overall trend of research related to computer vision and disabilities and explore the detailed research contents. To achieve this, the paper have modified the analysis categories based on previous research to suit the objectives of this study [13-15]. The details of the analysis categories applied to this study are shown in the [Table 1].

[Table 1] Analysis categories

Categories	Subcategories
Basic Information	Publication year(2019~2023), Publication language(English or Korean)
Application	Subject, Disability type
Computer vision methods	Object recognition, facial recognition, gaze detection, motion detection, gesture recognition, text recognition, emotion recognition
Device	Video, camera, sensors, robot
Analysis	Controlled environment, field experiment, testing, interview
Output	Results derived from research
Outcome	Changes or impacts resulting from research results

2.3 Inter-rater reliability

This study developed an Excel coding sheet structured around analysis categories. To guarantee a uniform comprehension of the analysis criteria, a consensus was established before initiating the coding process. Initially, three papers were collectively coded to enhance the reliability of their analysis. Subsequently, the remaining 20 papers underwent independent coding, and the results were cross-compared. Reliability was determined by calculating the percentage of items with consistent coding against the total sample items, resulting in an inter-rater reliability of 97%. Any discrepancies were reconciled through discussions, ultimately achieving a 100% agreement on all items.

3. Results

3.1 Overall Research Trends

This study analyzed 23 peer-review articles conducted between 2019 and November 2023, all of which provided detailed technical and algorithmic information on the use of computer vision technology in disability-related research. Overall characteristics of the included studies are presented in [Table 2] [16-38]. According to the analysis of computer vision technology used for individuals with disabilities, the majority of the research was published between 2019 and 2021 (9 studies in 2021, 39.1%; 7 studies in 2019, 30.4%; 5 studies in 2020, 21.7%). The findings also indicated that there were relatively more studies published in English (15 studies, 65.2%) than those published in Korean (8 studies, 34.8%).

[Table 2] Characteristics of included studies

No.	Article (Year)	Language	Subject	Computer vision methods	Device	Analysis	Output	Outcome
1	Vyas et al. [16]	English	Training Set 1 68 ASD/68 TD Children Training Set 2 101 ASD Children	State-of-the-art human pose estimation	Video (2D Mask R-CNN)	controlled environment	High Accuracy Correlation	Enhancing ASD Diagnosis with Posture Estimation
2	Piana et al. [17]	English	13 High-Functioning Children with ASD	Emotion recognition	RGB-D sensors	controlled environment	Task accuracy recognition accuracy expression accuracy	Enhancing Social Skills with Emotion Training Tools
3	Campbell et al. [18]	English	104 toddlers (16-31months, mean=22) 22 ASD/82 TD~DD	Movement detection (head movement)	Tablet built-in camera	controlled environment	Participants' attention: orienting in response to name calls	Boosting Social and Communication Skills in ASD
4	Shi & Zhao [19]	English	Task 1 Photo-Taking 22 ASD / 22 TD Task2 Image Viewing 20 ASD / 20 TD	Gaze detection image analysis Multi-Modal Behavior	Camera	controlled environment	Improved Performance in Photo-Taking and Image-Viewing	Improving ASD Detection through Behavioral Analysis in Children

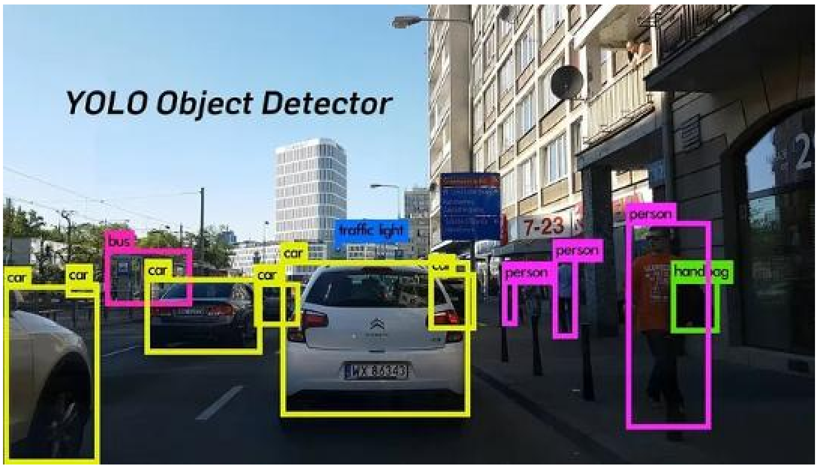
5	Mehmood et al., [20]	English	Mild & Min ASD Children(mean=8.3)	Gaze detection	Multi-robot	controlled environment	Dominance in visual space Robot Interaction & Brain Activity	Assessing Brain Dominance in Visual Processing to Improve Disorder Insight
6	Wang et al. [21]	English	8 Participants 5 TD Adults 3 Children (2 ASD, 1 TD)	Gaze detection(mutual), Gesture recognition	Camera, Sensors	controlled environment	Expressing Needs with Index Finger Pointing (ENIFP)	Validating ASD Screening Efficacy with ENIFP
7	Kunhoth et al. [22]	English	Blind or Nearly Blind Participants) (Ages 20-60)	Motion detection (localize the position)	CamNav, QRNav	field experiments	Accuracy Usability	Enhanced Indoor Navigation System for the Visually Impaired
8	Murali et al. [23]	English	27 Participants 6,600 Gestures Total (4,600 Training, 2,000 Validation)	Image analysis, Convolutional Neural Networks(CNNs)	Web-cam Microsoft Kinect	testing	Accuracy Jaccard Index	Enhanced ASL Recognition for Deaf Communication Improvement
9	Li et al. [24]	English	NYC Traffic Intersections	Motion detection	A portable GPU unit, the Nvidia Jetson TX2	field experiments	Portability recognition accuracy computing efficiency	Improved Walking Env. & Independence for Visually Impaired
10	Moro et al. [25]	English	10 Chronic Stroke Survivors (7F, 3M) Hemiparesis(mean=62.75)	Motion dectection (markerless pose estimation)	Stereo photo grammetric system, MARTDX, RGB camera	field experiments	Spatio-temporal parameters Relative joint angles	Enhanced Mobility & Autonomy for Visually Impaired
11	Kim et al. [26]	English	Bus Door Location & Direction	Object recognition, motion detection, gaze detection, YOLO	IMU sensor	field experiments	Proper door position	Improved Pedestrian Env. & Independence for VI
12	Hwang & Kim [27]	Korean	Disabled Drivers Using Accessible Parking	Image analysis YOLO, CNN, OCR	Raspberry Pi	Mixed	Increasing the recognition rate of Korean characters	Disability Env. Improvement via Accessible Parking Identification
13	Juneja et al. [28]	English	Deaf & Lang. Impaired (Sign Users)	Gesture recognition, CNNs	Real-time video frames	testing	Prediction accuracy	Improved Communication via Sign Recognition System

14	Drimalla et al. [29]	English	37 ASC 43 Neurotypical Control Group	Facial recognition, Emotion recognition	Video Web-cam	controlled environment	Facial Expression Imitation and Emotion Recognition Correlation	Enhanced ASD Social Interaction via Facial Expression Imitation
15	Cho et al. [30]	Korean	Mobile Obstacle Detection System	Object recognition, YOLO	Camera (smartphone)	testing	Object Detection Functionality	Independence for VI Pedestrians
16	Lee & Moon [31]	Korean	Food Photographs	Image analysis, YOLO	Camera (smartphone)	testing	Identifies and Announces the Food in the Image via Voice	Enhanced Daily Living Independence for the Visually Impaired
17	Kim et al. [32]	Korean	Barcode, Expiry Date Data	Image analysis, YOLO, OCR	Camera (smartphone)	testing	Classification of the expiration date accuracy	Improved Independence for VI Daily Living
18	Oh & Bae [33]	Korean	Object Block Photos, Environmental Data	Object recognition, YOLO v3	Camera (smartphone)	field experiments	Performance of the image recognition, Precision	Enhancing VI Pedestrian Env. & Independence
19	Choi et al. [34]	Korean	3 VI Kitchen Vision Sensing System	Object & gesture recognition, Image analysis, YOLO v2	Computer	interview, testing	Detection Probability, Average Precision	Enhancing VI Daily Living Independence
20	Jung et al. [35]	Korean	Product Image Dataset System Dev. & Perf. Evaluation	Object recognition, Image analysis, YOLO v5	Computer	testing	Performance Mean Average Precision	Improving Independence for the Visually Impaired
21	Jung et al. [36]	Korean	5 Types of Beverage Cans	Object recognition, Image analysis, CNN, YOLO v5	Camera, Speaker	testing	Accuracy Voice Output	Improving Independence for the Visually Impaired
22	Jang et al. [38]	English	ASD Risk Children TD Children	Facial recognition, Gaze detection, Video analysis, Face recognition	Video, Mobile application, Camera	testing	Assess Engagement and Emotional Responses in Toddlers with and without ASD	ASD Risk Prevention via Risk Behavior Analysis
23	Ascari et al. [39]	English	Motor Impaired Language Impaired	Gesture recognition, SVM, CNN	Computer, Web-cam	testing	Estimation of prediction error	Enhancing AAC and Communication Improvement

3.2 Computer Vision based Approaches for Individuals with Disabilities

Out of the 23 studies analyzed, the majority (10 studies, 43.5%) focused on using computer vision technology for individuals with visual impairments. This was followed by ASD (8 studies, 34.8%). The remaining studies (3 studies, 13.0%) focused on other conditions, while only 2 studies (8.7%) were related to hearing impairment. The detailed analysis results were presented, focusing on how computer vision technology is applied to improve the quality of life for individuals with disabilities as follows.

Visual Impairment. Various computer vision technologies are being used to support individuals with visual impairments. These technologies include motion detection, object recognition, gaze detection, and gesture recognition. Several studies have shown that these technologies can help people with visual impairments to move independently [22][24][26][30-36]. The YOLO algorithm, which is primarily used for real-time object recognition, was found to be the most commonly used technology in these studies (8 out of 10). For example, YOLO, short for 'You Only Look Once,' is a popular object detection algorithm in the field of computer vision. It is known for its speed and accuracy in real-time object detection tasks. Unlike traditional algorithms that perform object detection by sliding a window over an image, as shown in [Fig. 2], YOLO approaches this task as a regression problem by dividing the image into a grid and predicting bounding boxes and class probabilities directly [37].



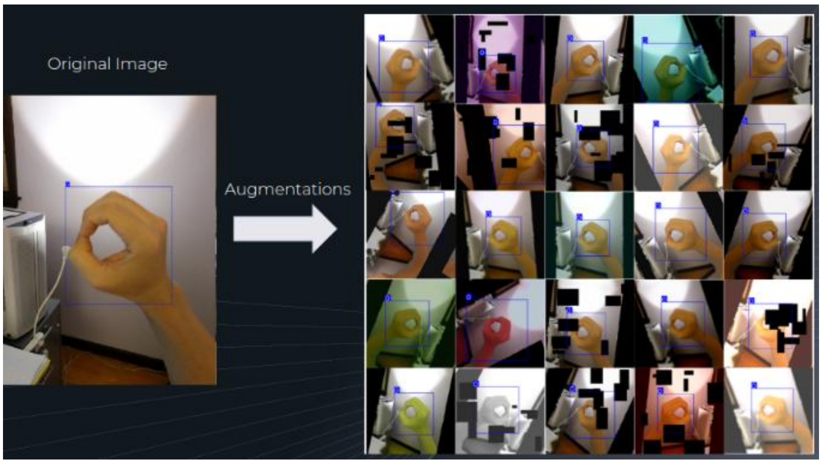
[Fig. 2] YOLO Object Detector

ASD. Computer vision technologies employed for ASD include pose estimation, emotion recognition, movement detection, gaze detection, gesture recognition, facial recognition. Studies utilized these technologies, based on images and video footage, to comprehend the behavioral characteristics of individuals with ASD [16][19-21][38]. Through pose estimation, gaze detection, and facial recognition, they enhanced early detection and diagnosis accuracy. Additionally, technologies such as emotion recognition, movement detection, and facial recognition have been applied to improve the social skills of individuals with ASD.

Other Condition. In addition to computer vision technologies, research has been conducted targeting individuals with cognitive impairments, stroke, as well as motor and language disorders. A study utilizing motion detection was conducted to enhanced mobility and autonomy of stroke patients [25]. Another research utilized gesture recognition to improve Augmentative and Alternative Communication (AAC) [39]. AAC refers to various methods and tools used to supplement or replace speech or writing for individuals who have difficulty communicating verbally or in written form. AAC systems are highly individualized, aiming to provide individuals with effective means of expressing themselves and engaging with others in their environment. They are often developed in collaboration with speech-language pathologists, educators, and other professionals to ensure they are personalized to the user's specific communication needs, abilities, and preferences. As shown in [Fig. 3], one of the simplest forms of AAC devices is the picture board. These boards utilize symbols or images to represent messages and are particularly useful for individuals with limited vocabulary or literacy skills. Communication books, another type of AAC device, employ symbols, images, or text to support those with communication challenges [40]. Lastly, a research was carried out to recognized accessible parking spaces for individuals with disabilities using algorithms such as YOLO and OCR [27].

[Fig. 3] The ultimate guide to AAC device

Hearing Impairment. Computer vision technologies have yet to be extensively used for hearing impairment. Unlike studies on ASD and visual impairment, only two studies have been conducted using CNN algorithms to recognize sign language and convert it into spoken language [23][28]. The aim of these studies is to improve social communication between individuals without disabilities and those with hearing impairments. Current application can be shown in [Fig. 4] that American sign language can be read through computer vision and machine learning [41].



[Fig. 4] Reading American Sign Language with Object Detection

4. Discussion

This study conducted a systematic literature analysis focusing on research involving computer vision technology applied to individuals with disabilities over the past five years. After analyzing 23 studies published during this period, the research primarily focuses on enhancing the independence of individuals with sensory impairments including visual and hearing impairments, in their daily lives. Specifically, there is a notable emphasis on research targeting ASD, aiming to understand their characteristics for improved diagnostic accuracy and facilitation of interpersonal interactions. The results highlight that computer vision technology has significantly contributed to enhancing the independence of individuals with disabilities who have historically depended on human assistance. Moreover, it has enabled a more accurate analysis and understanding of the unique characteristics associated with specific disabilities, fostering the creation of a more inclusive society.

The results of this study demonstrate the innovative potential of modern computer vision technology in the field of disabilities. The findings are expected to provide valuable insights into future technological research directions and development possibilities, aimed at enhancing the quality of life for individuals with disabilities. There are many individuals facing daily life difficulties due to various types and degrees of disabilities beyond what was analyzed in this study. The study reflects that innovative technologies such as computer vision technology will continue to be implemented in the field of disabilities to advance it further. Such technologies are expected to contribute significantly towards improving the daily life of individuals with disabilities.

While explaining the benefits of computer vision technology, the study may not deeply explore accessibility challenges or limitations faced by certain disability groups in utilizing such technologies. Thus, future studies can extend to focus on practical implementation strategies to ensure the seamless integration of computer vision technology into daily life for individuals with disabilities, taking into account user preferences, usability, and training requirements.

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