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Advancements in Robotic Systems for Sign Language Representation: A Review

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Abstract
When compared to spoken language, sign language offers a rich linguistic medium that is essential for the deaf and hard-of-hearing community. In order to close the communication gap, there is a great need for the development of robotics and robotic hands that are capable of accurately understanding and replicating sign language gestures. In this review paper, academic research and technological advancements are integrated. A variety of robotic system development methods and tools are presented, and used to interpret and create sign language, it also covers the difficulties and potential uses of these systems' technical advancement. Robotic systems can represent sign language in a variety of ways, including humanoid robots, signing avatars, robotic arms, robots that can be remotely viewed, gesture-controlled robots, and custom-built systems. Each has advantages and disadvantages, and the choice is based on the specific use case and requirements. Also, the paper discusses how human-robot interaction improves sign language representation and how robotic systems can help deaf and hard-of-hearing people learn, It shows how they affect learning and life. These systems can be used in research, education, and interactive settings. The comprehensive review of robotic systems for sign language representation will help researchers and practitioners advance inclusive communication technologies.

Keywords: Sign Language, Humanoid Robotic Arm, Android, Robotics, 3D Printing, Communication, Deaf, Disability, Dumb, DeafBlind, Hardware, Mobile app

Introduction

Sign language (SL) is a visual and gestural communication method primarily used by deaf or hard of hearing individuals. It's a form of natural language that differs from spoken language in its structure and is used differently in different nations and regions [1]. Despite their effectiveness, can be challenging for hearing individuals who don't know how to use it well. Since the number of people with normal hearing who are conversant in sign language for the hearing impaired is currently quite small. Therefore, more people need to learn sign language if they want hearing-impaired people to participate in social activities more [2]. In relation to signs, a sign language consists of two distinct components, namely the manual and non-manual components. Manual components of manual signs encompass hand movement, orientation, location, and shape. The non-manual components of signs encompass body posture, mouth gestures, and facial expressions. The majority of signs are communicated through manual components [3]. Hand gestures or hand movements are one of the parts of manual signs. Depending on the application, hand gestures can be either static or dynamic. For example, static gestures involve the hands being in certain positions, while dynamic gestures involve the hands doing certain things and moving quickly through a series of positions [4]. There are various types of sign languages used by various nations, such as: The Arab world [5], USA [6],Turkey [7], Germany [8], Spain [9], Iran [10], and so on. so It is crucial to establish a robust system that can translate spoken language into sign language for easy and mutual communication between hearing-impaired and hearing communities. Several studies have concentrated their attention on deaf people who use sign language as well as on DeafBlind people who use tactile sign language (t-SL)[11], the importance of robot embodiment in the teaching process[12], supplying an inclusive educational system for children[13][14], enhancing accessibility and support[15], human-machine interaction using open technologies[16], image recognition [17] and vision- based interaction[18], etc.

The important topic of robotic sign language systems will be introduced in this paper. This paper's goal is to present the most significant studies that have been done on this topic using the most significant technologies, with a focus on the years 2014 to 2023. This paper is organized as follows: Section 2 reviews some related literature, Section 3 Proposed robotic system design , Section 4 Robotic Systems Used for Sign Language Representation, Section 5 presents an extensive and in-depth analysis of the topic at hand, and Section 6 offers a conclusion.

1. Literature Review

The development of automatic translation systems for Sign Language (SL), specifically American Sign Language (ASL), Turkish Sign Language (TSL), Arabic Sign Language (ArSL) and other sign languages, has received considerable attention and has been the subject of several studies in this domain.

Gül [1] aimed to create a humanoid robot for teaching Turkish Sign Language, focusing on improving human-robot interaction and identifying potential shortcomings in future research. The robot used deep learning methodologies, three servo motors, and acoustic data analysis. Speech recognition used Viterbi search and additional information sources, while decoding involved Hidden Markov Models, phoneme sequences, word lists, and language models. The research was limited due to the COVID-19 pandemic, with a sample size of eight hearing and speech-impaired individuals.

Aliwy & Alethary [5] offer the largest known dictionary for Arabic Sign Language (ArSL), a 3D avatar-based dictionary with about 3000 signs. This allows written text to be converted into sign language and makes it accessible to deaf people in Arabic-speaking countries. The free tool offers a visual interface for translating between Arabic and American Sign Languages and allows for further exploration and development of ArSL. Our dictionary was based on the League of Arab States (LAS) and Arab League Educational, Cultural, and Scientific Organization (ALECSO) unified Arab dictionary.

Kolli et al. [6] present a real-time ASL interpretation system using machine learning, image processing, and computer vision to improve efficiency and message detection time, with a gesture recognizer and robotic hand for affordable and effective communication.
Two methods are used to integrate a robotic hand for ASL hand gestures. First, a machine learning model predicts alphabets and executes finger positions-based hand movements. Second, real-time hand gesture replication and ASL detection occur independently. Step two replicates gestures using finger landmarks.

Gül [7] discusses the development and use of the EC-Tema humanoid robot for teaching Turkish Sign Language (TSL) to speech and hearing-impaired individuals. The robot was designed and programmed using Python and Arduino, and the Google Speech Recognition library. Some shortcomings were identified, such as insufficient finger flexion for some number expressions. The paper emphasizes the robot's potential as an educational tool for individuals with hearing and speech impairments.

Homburg et al. [8] the research examines humanoid robots as sign language translators. InMoov's two arms were 3D-printed with index finger and thumb joints to facilitate sign language expressiveness. German sign language and a voice recognition system were programmed into the robotic arms. If a similar word or term appears, the system expresses the pre-programmed sign language gesture, otherwise it spells out each letter. It does this by comparing input with database data. This article developed a RoboSign Language Translator (RSLT) to help deaf persons integrate into everyday life.

Gago et al. [9] look into how humanoid robots, specifically TEO, can be used to make Cyber-Physical Systems (CPS) easier for people who are deaf or hard of hearing to use. When compared to the use of screen subtitles, the use of robots with robotic arms and hands facilitates communication using Spanish Sign Language (LSE).
The study, which included 16 participants as its sample size, focused on topics like dactylology, basic vocabulary representation, and end-user satisfaction in the context of sign language representation.

Zakipour et al. [10] provides a comprehensive overview of RASA, an affordable upper torso robotic platform designed to teach hearing-impaired children in Persian sign language. The discussion includes various aspects of RASA, such as high-capacity manual arm systems, cost-effective development, simplified maintenance procedures, design principles, and mechatronic design considerations. As well as recommendations for future studies on the effectiveness of RASA as a sign language teacher for deaf children's interaction and learning skills through methods Game-based teaching and evaluation of a robot's accuracy in producing signs in Persian sign language.

Johnson et al. [11] TATUM, a low-cost robotic hand for tactile American Sign Language (ASL) communication, is introduced. created for deaf and deaf-blind people. Using the Interpres application programming interface (API), provided by a cloud service, TATUM, a 3D-printed device, can convert electrical device inputs into servo sequences for generating ASL signals. This technology mimics human hand gestures and IDs well in visual validation trials. Elbow mechanism and wrist capture range are possible improvements.

Meghdari et al. [12] present RASA, a robotic platform created especially to improve the educational experience of kids with hearing loss by concentrating on Persian Sign Language (PSL) instruction. is a social robot that can interact with people in real life because it is outfitted with interactive features. In order to determine RASA's capability to recognize PSL signs, this study evaluates the hardware architecture and performance. The recognition rates of particular signs that the robot was able to recognize are shown in the paper. The appearance, perceptive, cognitive, PSL teaching, and kid engagement of RASA are all being improved by new research.

Adeyanju et al. [13] Three servo motors were used to construct a working prototype of a robotic hand for communicating in American Sign Language, along with nearby, readily available materials. The hand, the first ASL robotic hand, was constructed from low-cost domestic components and was driven by servo motors and an ATMEGA 2560 microcontroller board. It makes use of an Android mobile application with speech recognition capabilities. In the future, two-handed robot prototypes will be created.

Maliki et al.[14] describe a robotic platform that teaches sign language using realistic arm and finger movements. It can be an interactive tool for kids or an automated system that instantly translates spoken language into visual signs. To teach sign language as a general concept at a low cost, the project focused on open source design for accessibility. The robot must have enough degrees of freedom and range of motion to do sign language correctly and precisely. The InMoov robot used in this study has never been used a way before.

Paula et al. [15] The bidirectional translator focuses on text to Portuguese Sign Language (PSL) translation using a 3D avatar to enhance deaf people's communication and quality of life. The 14 sensors in the 5DT Data Gloves, which have a data collection rate of 100 samples per second, record hand movements and shapes. Support vector machines classify different hand configurations, while the 3D avatar reads the text and animates, mimicking how a human body would move. Because some PSL configurations only differ in the orientation of the palm, hand orientation is taken into account during translation.

Das et al. [16] The project's goal is to use open technologies to create an automated voice-to-Indian Sign Language (ISL) translator for the hearing impaired. A robotic hand prototype with inexpensive acrylic assembly is currently being made in order to mimic the sign language alphabet. Basic control is provided by the open-source Julius speech recognition engine, Raspberry Pi minicomputer, and Arduino UNO controller. On low-end PCs and embedded devices, Julius can recognize speech in real time while supporting Ngram, rule-based grammars, and Hidden Markov Model.

Jalaja and Shekar [17] present a cost-effective robotic arm that has been designed to facilitate the conversion of English text into American Sign Language symbols and vice versa. The system integrates image recognition technology and sentiment analysis algorithms that utilize a recurrent neural network (RNN) based neural network. This enables the classification of statements into distinct sentiments, specifically designed to accommodate individuals with speech impairments. Additionally, the system includes an auto-text completion feature, which enhances the convenience of typing.

R. Deepan et al. [18] describes a novel approach to control an intelligent hand that imitates human hand movement using a Raspberry Pi processor and vision-based interaction. For humanoid robotics, the hand has four degrees of freedom in its articulated fingers. Finger motion and hand gestures are accurately tracked by face subtraction and skin color detection. The mean shift algorithm monitors finger motion using video data. With a Raspberry Pi processor and camera module, this hand gesture-based control system performs admirably and precisely for in-the-moment hand control.

Chang et al. [19] The TATUM tactile American Sign Language (t-ASL) assistive technology uses a robotic hand and arm to sign complex ASL words and phrases. It uses gesture transfer, human motion recognition, and vision-based machine learning for secure communication and actuator control. By using the MediaPipe framework to estimate 3D human and hand poses, the system reduces the footprint of the forearm structure. Future plans include a multi-camera strategy, analysis, user feedback, safety evaluation, sensing integration, and user trials.

Al-Khulaidi et al. [20] SignBot is a 3D printed robot that can perform Malaysian Sign Language (MSL) using sequential servo motor arrays. The system includes a speech processing unit, a database of signals, microcontrollers, and actuators. The robot hands have detailed finger joints and small servo. A microphone interprets the speech signal, which is translated into text and sent to an Arduino via serial communication. Each string represents a signal for a specific servo motor movement. The servo motors execute the specified movements to perform the corresponding signal.

GÜL [21] describes a humanoid robotic arm that can display letters and numbers in American Sign Language (ASL) using Python programming and an Arduino control board. ASL signals' structure and constituent parts, including hand form, movement, mark position, palm direction, head direction, and facial expressions, were studied. Research shows that sign language may be properly imitated by robotic devices with minimal development costs and straightforward maintenance. The study highlights the use of open-source software and 3D printing to develop robotic systems that can be shared and produced using 3D printers.

Taryudi et al. [22] the design and creation of an Indonesian sign language display system that uses a hand robot and an Android app on a smartphone are described. The software development includes making an Android app that runs on a smartphone and using Arduino Mega and MIT App Inventor 2 to create the hand robot controller. To test the system, the letters and numbers on the screen are checked against the Indonesian Language Signalling System Dictionary (SIBI) using hand motions.

J. V. Torres et al. [23] present an experimental system that simulates sign language using a robotic arm, with the goal of enhancing communication and inclusion for Peruvians with auditory or non-verbal disabilities. Design, development, programming, and integration of hardware and software were all part of the study. In response to the need for specialized instruction for the community of people with hearing loss, researchers successfully constructed an articulated robotic hand with high flexibility. The practicality and adaptability of the system in using the robotic arm for sign language communication are highlighted in the paper.

Bulgarelli et al.[24] introduces a low-cost 3D-printable robotic hand intended for deaf and DeafBlind users to replicate hand poses in Sign Languages. The hand adds degrees of freedom for three fingers' abduction and adduction and a parallel spherical joint for the wrist to increase dexterity. For people who are DeafBlind, the PARLOMA project validates the hand and allows for remote sign transmission. The entire project—hardware and software included—is made available online under an open-source license, encouraging further development. A hand repeated Italian Sign Language signs and handshapes and improved sign recognition through visual feedback and adduction-abduction degrees of freedom.

Russo et al. [25] PARLOMA is a new system that lets DeafBlind people talk to each other from far away using Tactile Sign Language (t-SL). It recognizes hand shapes made in front of a depth sensor and makes copies of them with a robot hand. In order to perform t-SL remotely, the PARLOMA system combines computer vision and robotics. There were tests to see if the shapes of hands used in Italian Sign Language (LIS) could be recognized and sent to a robotic hand. This makes the LIS manual alphabet accessible to the DeafBlind community.

Wasim et al. [26] proposes a Pakistani Sign Language (PSL) system with two-way communication for the deaf. The system allows non-specialists to communicate with deaf individuals by translating written English into hand gestures using image processing. It does a spellcheck, breaks down text into tokens and subtokens, and generates gestures based on tokens. Communication between the two parties is facilitated by the system's ability to recognize hand gestures and translate them into text or audio.

Al-Khulaidi et al. [27] demonstrate how to use 3D printing to create robotic hands that can sign in Malaysian Sign Language (MSL). The aim is to facilitate communication between hearing people and hearing people in Malaysia. Robot hands have intricate joints thanks to servo motors that are controlled by an Arduino Mega. Recognition is improved and made more practical by integrating a speech-to-text translation system with Microsoft Visual Studio. The system has a front-end and a back-end that collaborate to convert recognized text into sign language for the robot.

Nihal et al. [28] describe a low-cost humanoid robot that can comprehend both medical signs and Bangla sign language (BdSL). The robot is trained on publicly accessible datasets, like the 950 images and 166 videos it uses, to achieve high test accuracies in image- and video-based recognition tasks. The robot will be enhanced in the future with 3D image capture technology, its degrees of freedom will be increased to mimic all BdSL and healthcare signs, and a dataset for word- or sentence-level BdSL recognition will be produced.

AKSOY et al.[29] This study aims to address the communication challenges encountered by individuals with hearing impairment. It proposes a solution that involves programming a robotic arm to execute Turkish sign language gestures, which are determined by input received through either voice or keyboard commands. The study employed a sample of 25 sign language gestures from Turkey and utilized Google's speech library for voice input and keyboard input to enact the movements via a humanoid robot arm. The study proposes that future investigations may enhance the data set and investigate more intricate movements that can be executed by the robotic arm.

El-Gayyar et al. [30] introduce a mobile-based framework that makes use of cloud computing to help the Arabic deaf community communicate with ease and independence. Arabic text is translated and communicated in real time using cloud computing, converted into Egyptian Arabic Sign Language (ArSL) , and displayed as a cartoon avatar on mobile handsets using speech processing techniques.
The mobile-based framework comprises three layers: data layer, service layer, and interface layer, each with its own data, service, and user interface. Future work includes creating a sign database with real human representation, GIF animated images, and mobile phone integration for reduced network streaming to allow deaf users to upload their own signs.

Kenshimov et al. [31] talk about a system that uses a touch sensor to understand the hand movements that a Kazakh robot makes while talking. System uses machine learning to make gesture recognition more accurate. The robot's movement is controlled by servo drives, which makes communication easy. Learning and experimentation are the system's two phases. In the learning phase, hand gestures are taught to the model, and in the experiment phase, the model is loaded and the robot is made to mimic the gestures. Additionally shown is the robot's fingerprint in Kazakh sign language, illustrating the viability of successful robotic systems that employ hand motions.

Gürpnar et al. [32] A humanoid robot with a sign recognition system for use with children who are hard of hearing or deaf is demonstrated in this work. It uses a deep learning-based approach that draws on long short-term memory (LSTM) as well as a traditional approach that uses a hidden Markov model and artificial neural network (HMM ANN). With the help of motion data collected from children who were deaf or hard of hearing and were fluent in Turkish sign language, the system was put through its paces on more than 150 test subjects. During the initial research, the data was gathered at the children's school.

Broura and Benabboub [33] The study results in the development of ATLASLang, a computer program that can translate Arabic text into Arabic Sign Language (ArSL). The system creates sign language expression video sequences using rule-based and example-based methodologies, morpho-syntactic analysis, and 3D human avatars. Fingerspelling animation and the use of a 3D Human Avatar in place of gif images are improvements. Additionally, there is a database of signs and translations for words that use fingerspelling but aren't already in the database. The database will grow and more ArSL rules will be added.

3. **Proposed robotic system design**

The technological systems for translating language into sign language in order to capture, process, and visually represent the input language in the form of sign language gestures and movements are made up of various components, as shown in Figure 1; these parts are referred to as robotic systems. The components and configurations of a system may alter depending on its intended use, complexity, and technological advancements.

A key element in translating spoken and written languages is the input device, with spoken languages using microphones[20] and written languages using physical keyboards[29], touchscreens, or text entry systems[13]. on other hand may be a camera[18] or sensor system[31][32] responsible for capturing gestures, movements, text or that must be translated into sign language.
A processing unit, such as a computer or microcontroller, analyzes input language, generates output in sign language, and uses algorithmic and machine learning techniques to interpret and generate the proper signs and gestures.

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These algorithms may use deep learning models[1] or linguistic rule databases, and they may be rule-based or machine learning-based. Motors and servos power the robotic limbs of the Gesture Generation System, which then perform sign language gestures. It may employ a humanoid robot[10] or a 3D avatar to simulate[33] . Some systems use a display system to show the user the sign language output, while others may have speakers or haptic devices to give the user auditory or tactile feedback[19].

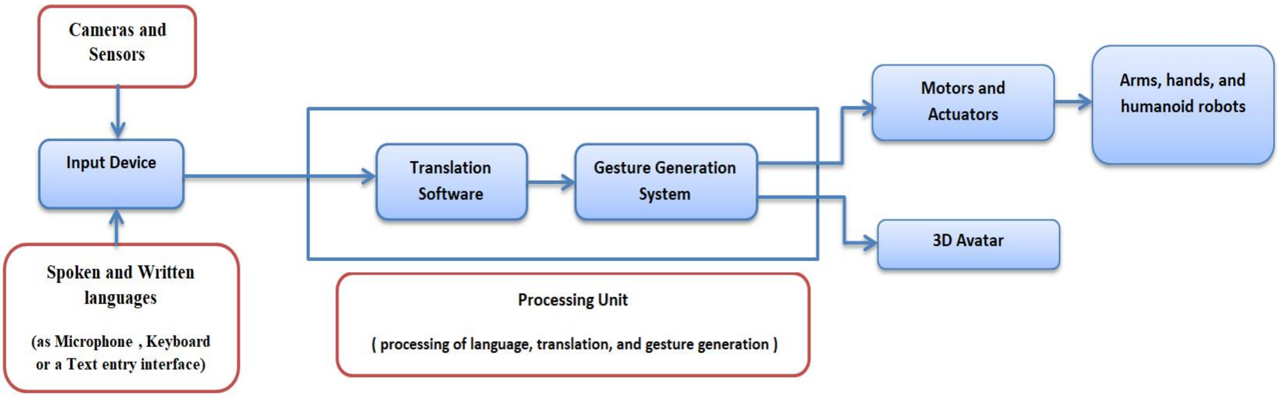

Figure 1 : The component parts of any robotic sign language system

4. Robotic Systems Utilized for Sign Language Representation

4.1 : Avatar-Based Systems

Sign language systems use animation or digital representations of people to show how people talk. These systems, not actual robots, can Sign language systems use animation or digital representations of people to show how people talk. These systems, not actual robots, can be added to platforms like websites and mobile apps for real-time contact .They can translate spoken or written language into sign language, which makes it possible for changes to happen right away. Recently, various animated avatar-related works have been created [5,15,26, 30,33].

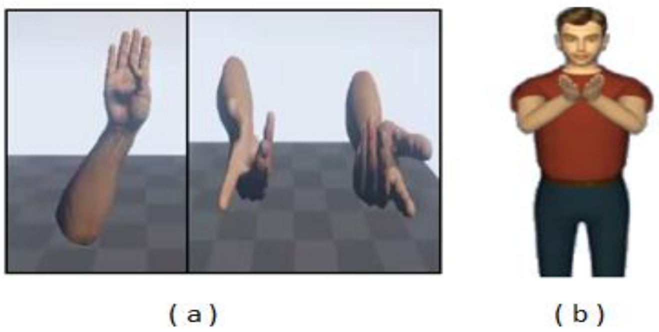

Figure 2: (a) shows the gestures for the letters "B" and "How" using Pakistan Sign Language (PSL)[26] (b) an example of generated signs “ كتاب [book] “ [5]

4.2: Tactile Feedback Systems

Technologies called tactile feedback systems use vibrations, pressure, or texture to replicate the sensation of touch. They are used in a variety of settings, including human-robot interaction ,virtual reality and assistive technology. These devices may improve DeafBlind communication by providing vibrations or tactile clues that match to movements or phrases in sign language. This improves sign language interpretation for DeafBlind people, improving engagement and communication.

To use Tactile sign languages(t-SL), the DeafBlind(DB) user must place their hand on the robotic device. This makes traditional designs dangerous and weak. Users of (DB)s could get hurt if their fingers get caught in closing joints or in external wires. Since they can't see how the system is set up, the danger is even higher. To address these issues, some research proposes a low-cost, anthropomorphic, 3D-printed robotic limb system (Arm [19] - Hand [11,24,25]) that signs Tactile sign language (t-SL) with an appropriate tangible referent. The user can safely position their palm on the device due to the system's robust construction as shown in figure 3 . Because it imitates the organic movements of the human arm and hand, the anthropomorphic design makes it simple for database users to comprehend and operate.

Figure 3: (a) The proposed humanlike arm hand system for DB communication with t-ASL[19], (b) blindfolded human who is unfamiliar with ASL [19]

4.3: Humanoid Robots Systems

Humanoid robots are employed for the purpose of sign language interpretation and communication, thereby providing assistance to individuals who possess hearing impairments or are afflicted with partial deafness. With the integration of sensors, actuators, and artificial intelligence algorithms [31], these devices possess the capability to interpret sign language movements through the utilization of computer vision [28] and gesture recognition technology.

These robotic systems have the capability to generate signed messages as well as translate written or spoken language into sign language, rendering them valuable in the domains of assistive communication [32], education [12] , and healthcare. Like humans, they have a head, torso, arms, and legs as shown in figure 4. Many research papers have been written on this subject [1,7,9,10,20].

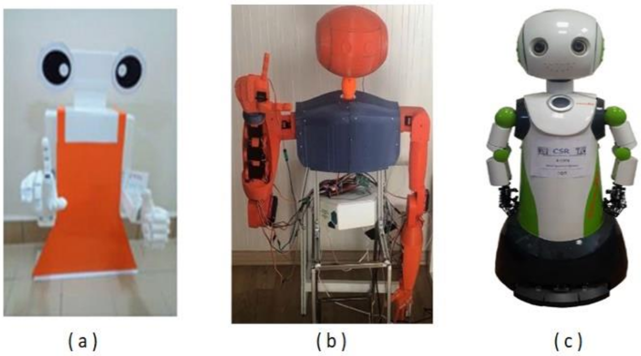

Figure 4: (a) The performance of SignBot[20] ,(b) Printed EC-Tema humanoid robot [7] , (c) Robovie R3 [32]

4.4 : Robotic Arms and Hands

A robotic system consists of a hand and /or an arm that are made to mimic the motions and gestures of a human hand[13][14]. The dexterous movements and gestures used in sign language communication are precisely replicated by the robotic hand. On the other hand, the robotic arm consists of the system's entire arm-like structure, which also includes the wrist, elbow, and shoulder joints as well as the hand or end effector as shown in figure 5 (for robotic hand and arm components) and figure 6 (Illustrations of some designs) . They both cooperate to make it possible to imitate sign language gestures, but they each have unique responsibilities and capabilities within the system as a whole. Research papers on this topic abound [6,8,11,13,14,16-19,21-25,27,29].

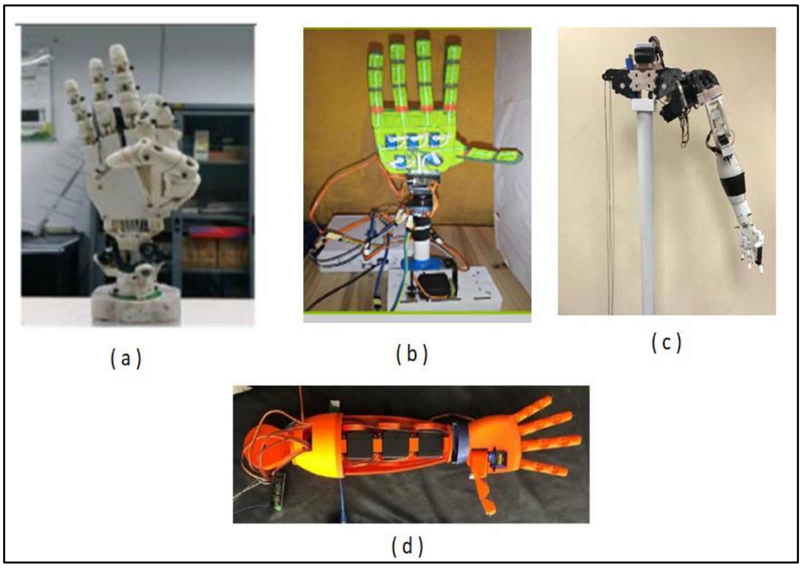

Figure 6 : Illustrations of some designs (a) Hand robot-shape of alphabet “F” [22] , (b) Robotic Hand[13] ,(c) The Left Arm of the Robot [14] , (d) Robot Arm shape [21]

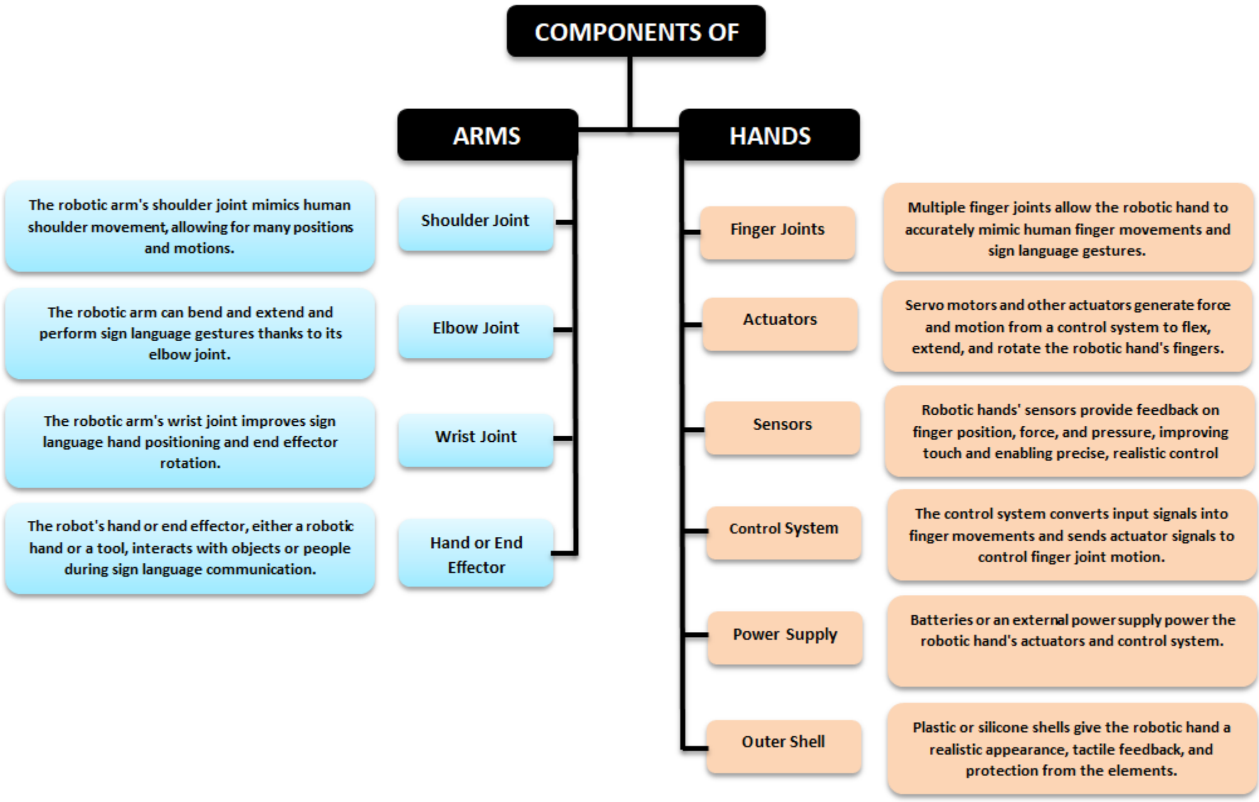

Figure 5: Robotic Arm and Hand components

5. Substantial Analysis (In-depth analysis)

This section provided a thorough analysis of the relevant work. According to the total number of studies conducted on sign language representation systems, statistics are presented in percentage form in figure (7).

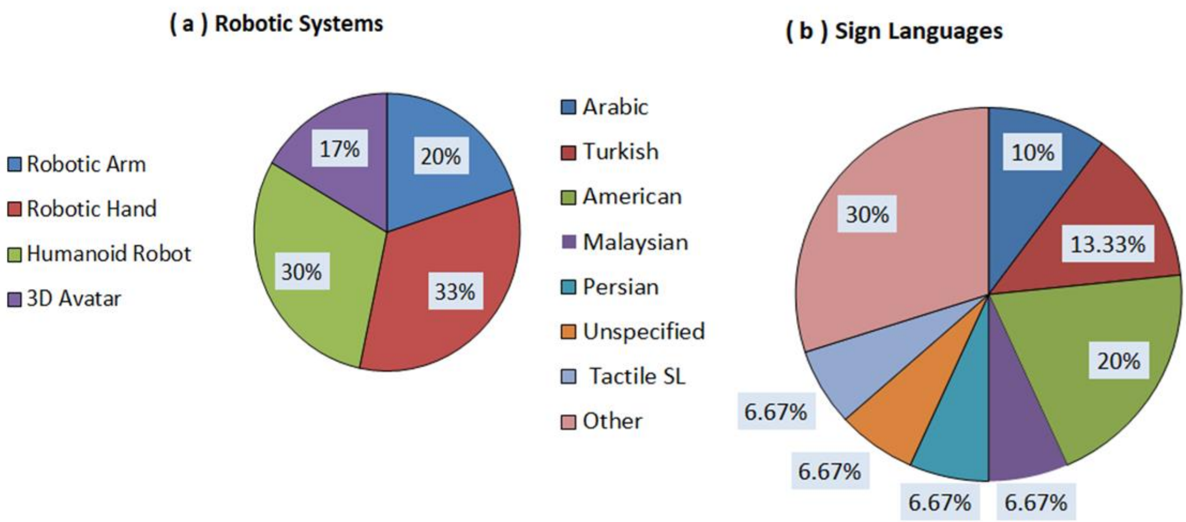

Figure 7 : (a) percentage of studies conducted using robotic systems (b) Percentage of study work done based on sign languages

In Chart A, the majority of sign language representation research was conducted using a robotic hand (33%), a humanoid robot (30%), a robotic arm (20%), and a 3D avatar (17%), according to the results. According to Chart (b) the present study investigates the existing body of literature pertaining to diverse sign language types across the globe, with a particular emphasis on the pioneering research conducted in American Sign Language (ASL). Notably, ASL has emerged as the primary country contributing to scholarly investigations in this domain, accounting for approximately 20% of the published articles. The Turkish sign language was with a percentage of 13.33%, followed by Arabic with a percentage of 10%. Malaysian, Persian, tactile, and Unspecified sign languages each accounted for 6.67% of the articles.

The article additionally references a study that highlights the presence of 30% include various sign languages, such as Indonesian, Portuguese, Bengali, Pakistani, Spanish, German, Kazakh, Peruvian, and Indian sign languages.

The summary of the literature study on sign language detection systems is shown in TABLE 1, TABLE 2 and TABLE 3. The tables show the reference paper, language, Input modality, Translation Software, Methodology, Accuracy, Challenges, Limitations and Design included (Model , Degree of Freedom (D0F) , number and types of motors, , and microcontroller).

5. Conclusions

The literature review indicates that developing robotic systems that can represent sign language is a challenging task requiring state-of-the-art hardware and software. The main goal is to make human-robot interaction usable and accessible for those who are hard of hearing or deaf. Positive outcomes have been seen when deaf children are taught sign language by social robots. One technique uses gestures and visual cues to represent sign language, allowing robots to communicate with users in their own language. These systems enable autonomous interaction without the need for teachers or researchers thanks to real-time sign recognition technologies built in. For sign recognition modules, a wide range of proposed strategies have been made.

It is important to take into account a number of factors when choosing the best robotic system to represent sign language, including accuracy, speed, adaptability to different languages, cost, and usability within the Deaf community. However, the representation of sign language in robotic systems is still a fairly new field of human-robot interaction. The ultimate objective is to develop universally useful products that cater to the accessibility requirements of sign language users and improve their interaction with robots.

TABLE 1 : Summarized literature review of Avatar-Based Systems – 3D avatar (Gesture Animations)

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate
[15]	2015	Portuguese Sign Language (PSL) / 10,000 words	Data Gloves	Machine learning algorithm (Support Vector Machines)	text-to-PSL translation using a 3D avatar, translator module division, PowerPoint slide translation protocol, and portability and cost reduction.	The system's dependence on certain devices and technologies may require ongoing updates and maintenance for optimal compatibility and performance.	Over 90% bidirectional and 91.7% real-time translation accuracy.
[30]	2016	Arabic sign language (ArSL) / 588 signs from various categories	avatar database with video representations of ArSL signs	Cloud computing , speech processing techniques	The paper's methodology emphasizes framework architecture, cloud computing, and speech processing for translation and communication.	Due to limited resources and the complexity of the Arabic language, it is difficult to provide assistive technologies for people with special needs in the Arab region, necessitating constant updates and modifications to the system database.	An efficient mobile-based framework with an average waiting time of 3.7-5.5 seconds for processing Arabic text and producing Egyptian Arabic Sign Language and an average usability score of 79.8 indicated user satisfaction.
[26]	2018	Pakistan Sign Language (PSL) / English Alphabets	Text and voice commands	Image processing techniques	Word-to-gestures conversion involves input, spelling and grammar checks, tokenization, image processing, and graphical display. The app lets users record and use gestures with an admin panel.	N/A	For 100 deaf people, all tests were repeated 10 times and showed high accuracy, except for some letters.
[33]	2019	Arabic Sign Language (ArSL) / database of signs	Text commands	SAFAR Platform , ALKHALIL morpho system	The ATLASLang MTS 1 machine translation system converts Arabic text to Arabic Sign Language using rule-based Interlingua and examples. It analyzes morpho-syntactic structure, converts HTML to XML, creates video sequences, finger-spells proper nouns, and reorders syntax.	The need for accurate morpho-syntactic analysis, sign language database availability, fully vowelized input sentences, and rule-based and example-based approaches.	Machine translation systems' accuracy depends on the input text's complexity, the sign language database's availability and quality, and the translation rules and methodologies applied.
[5]	2021	Arabic sign language (ArSL)/ 3000 signs	Dictionary of Arabic words	Hamburg Notation System (HamNoSys) Using eSign editor Software	To convert Arabic words into ArSL and create a sign dictionary, eSign editor software, HamNoSys notation system, and 3D avatar technologies were used. Tested signs were exported as SiGML scripts for 3D avatar interpretation.	Professionals are needed to create Hamburg notation (HamNoSys) signs.	In a dictionary test, 3D avatar technology outperformed video processing, and sign language experts gave the generated signs an average score of 4.3 out of 5.

TABLE 2 : Summarized literature review of Humanoid Robots Systems

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[10]	2016	Persian Sign Language (PSL)	N/A	Speech recognition and image processing modules	Development methodologies like design, software development, and testing are not mentioned. The robot's design, hardware, and features are highlighted.	Social humanoid robots for education may face safety, human-robot interaction, and continuous improvement and adaptation issues.	N/A	• Robot Assistant for Social Aims (RASA) • The robot has a 30 DOF upper torso platform, Dynamixel servo motors, Maxon brushed motors, and 13 DOF hand with 7 actuators. • Five fingers in each hand, totaling 7 DoF (4 with 1 DoF and 1 with 2 DoF).
[12]	2018	Persian Sign Language (PSL)	N/A	N/A	Design and build the RASA robot, compare it to other teaching methods.	A robot's wrist movement range and upper-arm design limited sign recognition scores, and mechanical design and integration of custom sensor modules and servo motors were needed	Users were asked to recognize video clips or images of selected signs to test the robot's PSL sign recognition. First-step recognition averaged 77%.	• RASA (Robot Assistant for Social Aims) • 29 DoF • Servo motor
[9]	2019	Spanish Sign Language (LSE)	developers' programming languages or GUIs	N/A	Dactylology and vocabulary recognition tests assessed hand signing and robot communication precision. Participant satisfaction was measured using comprehension tests and data analysis to understand user needs.	Sign language reproduction is difficult due to the lack of facial expressions and non-manual markers, but advances are needed to meet the growing demand for more nuanced communication	TEO's humanoid robot understood 83% of vocabulary, including the most difficult words, and 62.5% of the lowest words	• TEO is a full-size humanoid robot with 28 DOF and two actuated hands. Current Dextra TPMG90-2 has 15 DOF and 6 actuators. TEO has two 6-DOF arms
[32]	2019	Turkish sign language (TSL) / 200 samples	Kinect sensor	ANN-HMM technique and a deep learning LSTM technique	Traditional ANN-HMM and deep learning LSTM methods based on Kinect sensor data are presented for sign recognition. Data preparation methods straighten time steps, format training data, and add Gaussian noise	The physical and computational limits of a robotic system, overcoming tracking problems with other kids, and the need for cost-effective real-time solutions	In offline setup, HMM ANN was 97.97% accurate and LSTM 95.95%.The HMM ANN model was 56.23% accurate in real-time interaction.	• Robot Sign Tutor(Robovie R3) • standard version of the Robovie R3 humanoid robot → 17 DoF • A modified Robovie R3 humanoid robot with five-fingered hands was used, adding 12 wrist and finger degrees of freedom for a total of 29
[20]	2019	Malaysian Sign Language (MSL) / number, letters, and emergency words	speech commands	C language using Microsoft Visual Studio	Microsoft Visual Studio converts microphone speech into text, and a database retrieves the servo motors' sequential mechanism.	N/A	SignBot performed A, B, H, I, L, S, U and 1–5 in MSL during testing.	• SignBot • Arduino • 12 servo motor (8 for the right hand and 4 for the left hand)

TABLE 2 : Summarized literature review of Humanoid Robots Systems (contin.)

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[7]	2021	Turkish Sign Language (TSL)	N/A	Python and the Arduino software	EC-Tema used GSR sound processing to recognize normal voices for educational purposes, with promising results.	In some numbers, EC-Tema, a prototype humanoid robot, struggles with finger and wrist flexion.	showed expressions for 0-10 but struggled with 2-7	• EC-Tema. • 23 DoF (10 for each arm+ 3 for head)
[28]	2021	Bangla sign language (BdSL) 38 Bangla and 10 medical American sign language dictionary signs	Real-time video or image input is captured by the RGB-digital camera.	Recurrent neural network (RNN) and Convolutional neural network (CNN) for deep learning model	Deep learning models and feature extraction from video and image data are used to recognize medical signs using RNN and CNN	The robot's 15-DoF hand movements, 3D printing of soft materials, and anthropomorphic appearance limit its ability to mimic all BdSL alphabets. It accurately mimics 16 of 38 BdSL dictionary signs	Video-based medical sign recognition was 87.5% accurate, while image-based Bangla sign language recognition was 98.19% and 93.8% accurate	• 3D printed with soft material • 43 (DoF) which includes two 15 DoF hands • Arduino Uno Microchip ATmega328P • 23 servo motor (sg90 , MG995)
[31]	2021	Kazakh sign language	Touch Sensor	Machine learning methods	Acoustic phonemes, Fourier transform, DCT, ResNet, decoder, and search manager sub modules are used.	N/A	Over 98% recognition accuracy and 3ms detection time are achieved by the system.	• an open source 3D printed design," InMoov robot" • 50 DoF • Arduino Mega 2560 • 28 servo motors (MG996R , HITEC ,HS805BB)
[1]	2023	Turkish sign language (TSL) / 50 sign (11 numbers, 29 letters, and 10 daily activities)	Text and speech commands	Python and Arduino programming languages	Deep learning techniques	Need to improve wrist and finger flexion, facial expression mimicking, addressing challenges in symbolizing certain letters, and professional robot cost	All participants didn't understand some expressions, requiring precise finger manipulation and coordinated muscle and tendon control	• EC-Tema • 23 DoF (Each arm of the robot had 10 , head of the robot had 3) • Arduino

TABLE 3 : Summarized literature review of Robotic Arms and Hands

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[25]	2014	tactile Sign Language (t-SL)	low-cost depth sensor	Recognition Algorithm	The Robot Operating System (ROS) framework lets the system remotely transmit and control robotic interfaces and perform gesture acquisition, recognition, conversion, and synthesis	N/A	A DeafBlind experiment showed the system's recognition module accurately recognized hand-shapes (88.14%) and reproduced the LIS manual alphabet (73.32%)	• Parloma • One Robotic Hand • PALLOMA's robotic hand has one DoF per under actuated finger

TABLE 3 : Summarized literature review of Robotic Arms and Hands (contin.)

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[18]	2015	Unspecified language	Video data captured by a camera	Mean shift algorithm	Uses a Raspberry Pi processor, mean shift algorithm, and a single cable tension design with DC servo motors to track finger movements and extract hand gestures under vision	N/A	N/A	• One Robotic Hand • Raspberry Pi Processor • 5 DC Motors
[24]	2016	Unspecified language	N/A	N/A	inexpensive 3D-printing Dexterous sign language robotic hand with parallel spherical wrist. Systematic kinematic analysis of hand movement and degrees of freedom, validated by PARLOMA	N/A	With 90% accuracy, a hand reproduced Italian Sign Language signs and handshapes.	• An open source 3D printed design " InMoov" robot • One Robotic Hand • Arduino UNO
[14]	2017	Unspecified language	-----	My Robot Lab (MRL) built and programmed the robot, while the Raspberry Pi programmed the arm	presents a 3D-printed robotic platform that uses realistic arm and finger motions to teach sign language and reduce classroom overstimulation, especially for children	Children learning sign language may be overstimulated, and 3D-printed robotic arm parts were difficult to assemble.	N/A	• Open source 3D printed "InMoov" • Two Robotic Arm • Fingers, wrists, shoulders, and biceps were controlled by HK15298B, MG996R, and HS805BB.
[27]	2018	Malaysian sign language (MSL) / alphabets, numbers and the emergency phrase	Speech	Microsoft Visual Studio (MVS) , C#	The design and implementation of SignBot's robotic hands, the integration of a speech recognition system, and the creation of a database of sign movements are the main topics of this paper	Due to its limited communication options and shoulder and wrist movement, the robot cannot perform most MSL signs, but this does not affect understanding	SignBot's speech recognition system was 93% accurate for 80 tested phrases	• Signbot an open source design retrieved from Thingiverse website • Two Robotic Hand • Arduino Mega or Arduino Uno • 12 servo motors(8 /4 Right /Left Hand)
[16]	2019	Indian Sign Language (ISL) / alphabets, numbers	Voice commands	Julius AI model	The robotic hand's design, the integration of the Arduino UNO controller and Raspberry Pi mini-computer, and the use of open technologies.	Speech recognition engine accuracy, complexity, hardware component cost and availability, full sign language gesture reproducibility, and sign language variation adaptability are system challenges	N/A	• Acrylic is used to make the hand assembly • One Robotic Hand • Raspberry Pi mini-computer , Arduino UNO • 6 servo motors

TABLE 3 : Summarized literature review of Robotic Arms and Hands (contin.)

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[22]	2019	Indonesian Sign Language (ISL) / letters and numbers	Text and voice commands	Arduino IDE, EasyVR Commander for signal processing, and MIT App Inventor 2 for Android app development	N/A	Limited movement capability, Cost and accessibility , Hardware limitations	System testing shows 80% accuracy	• An open source 3D printed design " InMoov" robot • One Robotic Hand • Arduino Mega 2560 • 11 servo motors
[8]	2019	German sign language (GSL) / every letter, numbers 1-20, and two-hand words	Voice commands	Python	RSLT was developed and evaluated by identifying features, prototyping, and testing participants' recognition and acceptance.	speech recognition limitations, sign language simplicity, sample size, and prototype improvement needs.	N/A	• The RoboSign Language Translator (RSLT) • Open source 3D printed "InMoov" • Two Robotic Arm • Arduino • 6 servo motor (One per finger and wrist)
[29]	2020	Turkish sign language (TSL) / 25 samples	sound or keyboard input	Google speech library, Python software	The Arduino and Python-detected and programmed humanoid robot arm used Google's speech library to convert TSL movements into audio	Sound input took longer than keyboard input for 25 (TSL) movements, suggesting hearing-impaired people may have trouble communicating in real time	The research found that keyboard input moved the robot arm 40% faster than sound input	• Open source 3D printed "InMoov" • One Robotic Arm • Arduino Tmega328P • 6 servo motor
[23]	2020	Peruvian Sign Language(PSL)	Voice command	An Android Studio-developed application	Design and development involved modifying joint materials to create a flexible robotic hand, and programming and hardware and software integration used an Arduino application for hand management	Despite human numerical processing and coordination limitations, the robotic arm had trouble assembling parts due to stress and low resistance	N/A	• robotic hand made of wood • One Robotic Hand • Arduino • 5 servo motors
[11]	2021	American Sign Language (ASL) / 26 letters	Interpres application programming interface (API)	C and Arduino libraries	The web application Interpres API stores 15 degrees of actuation and servo sequences, allowing the TATUM platform to mimic human hand size and feel	TATUM recognizes ASL hand shapes but misidentifies letters like G and Q, may not be suitable for all users, and lacks elbow movements, requiring improvement for safer tactile communication	Visual and tactile validations showed 94.7% and 71.7% recognition rates for the 26 handshapes, respectively.	• TATUM (Tactile ASL Translational User Mechanism • One Robotic Hand • Arduino • 15 DoF (10 to the fingers + 5 to the wrist and thumb)

TABLE 3 : Summarized literature review of Robotic Arms and Hands (contin.)

Ref.	Year	Language/ Input Sign	Input modality	Translation Software	Methodology	Challenges and Limitations	Results or Accuracy Rate	Design
[21]	2021	American Sign Language (ASL) / all numbers and letters	Text and voice commands	Python and the Arduino software	A robotic arm was used to analyze (ASL) letters and numbers to create a humanoid robot for teaching hearing and speech-impaired children ASL	N/A	N/A	• One Robotic Arm • 7 servo motors (2 thumb, four fingers, 1 wrist) • Arduino Uno
[17]	2022	American Sign Language (ASL) / English alphabets	-----	Image Recognition	Two-way communication, image recognition to translate English into ASL symbols, sentiment analysis using recurrent neural networks, and auto-text completion improve interaction	Sign language interpretation and sentiment analysis robotic arms face challenges like translating English alphabet symbols into ASL, noise, and model effectiveness based on training data quality	The model predicts 98.46%, 98.07% with DenseNet architecture, and 93% with emotional sentences	• One Robotic Arm • Arduino UNO • 5 servo motor
[19]	2022	American Sign Language (ASL) / complex ASL words and phrases	vision-based machine learning	Machine learning	TATUM fingerspelling hand on 4 DOF robot arm controlled by human motion recognition and gesture transfer. A blind user tested its tactile-based sign recognition, and novice sighted users tested its accuracy	User safety and optimal performance are still being worked on in the TATUM prototype. Small forearm and pear-shaped cam-style pulleys help it overcome obstacles	N/A	• One Robotic Arm • TATUM (Tactile ASL Translational User Mechanism) • 19 servo motors (GS-9025MG , FS5115M , RDS5160),Maxon • 20 DoF (4 for Arm + 16 for Hand)
[6]	2023	American Sign Language (ASL) / dataset created for all the alphanumeric symbols	From a live video, a hand image is captured	Python , OpenCV library	This study utilizes machine learning techniques, computer vision algorithms, image processing methods, and the incorporation of a robotic hand to replicate gestures.	Hand shapes and lighting make hand gesture recognition difficult. Creating a dataset of all American Sign Language alphabetical symbols for the machine learning model is laborious	The 24 alphabet dataset had 96.3% accuracy, but low-light backgrounds had minor errors. Robotic hand recognized 20 alphabet gestures faster than ASL.	• One Robotic Hand • Raspberry Pi mini-computer • 5 servo motors (MG996R , SG90)
[13]	2023	American Sign Language (ASL) / English Alphabets, numbers, selected common words	Text commands	The MIT App Inventor 2 mobile application development tool , the Arduino IDE microcontroller programming	N/A	N/A	Robot hand response time was 2 seconds and accuracy was 78.43%. System functionality, reliability, ease of use, efficiency, and portability were above-average (97%, 77%, 80%, and 83%)	• used locally sourced cost effective materials • One Robotic Hand • Arduino Mega 2560 • 8 servo motors (5 fingers, 2 wrist, 1 forearm) (sg90, Mg90s, MG996r)

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