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Sign language interpreting - relationships between research in different areas - overview

Barbara Probierz*†, Jan Kozak*†, Adam Piasecki* and Angelika Podlaszewska*
* Łukasiewicz Research Network – Institute of Innovative Technologies EMAG,
Leopolda 31, 40-189 Katowice, Poland
Email:barbara.probierz,jan.kozak,adam.piasecki,angelika.podlaszewska@emag.lukasiewicz.gov.pl
† Department of Machine Learning, University of Economics in Katowice,
1 Maja 50, 40-287 Katowice
Email:barbara.probierz,jan.kozak@ue.katowice.pl

***Abstract*—Translation from the national language into sign language is an extremely important area of research and practice, which aims to ensure communication between deaf or hard of hearing people and the hearing community. The article provides an overview of the most important research on sign language interpretation conducted in various research areas. The latest scientific and theoretical achievements were presented, which contribute to a better understanding of the subject of sign language translation and the improvement of the quality of translation services. Our main goal is to identify outstanding areas of interdisciplinary research related to sign language translation and to identify links between these studies conducted in different areas. The conclusions of the article aim to broaden the knowledge and awareness of sign language translation and to identify areas that require further research and development. The work is linked to a project related to the application of machine learning in increasing accessibility for deaf people.**

I. Introduction

SIGN language is an integral part of the lives of deaf people, enabling them to communicate, express their emotions and participate in society. Sign language interpreters are essential to ensure a balanced access to information and services for people with hearing impairments. Sign language interpreters play a key role in the transfer of information between deaf and hearing people, enabling full participation in various areas of social and professional life [1].

Sign language is a natural language that, like any other natural language, has its own grammar, vocabulary, and sentence structure [2]. There are many different sign languages in the world, each with its own unique characteristics. Therefore, translating from a national language into a sign language requires not only knowledge of the sign language, but also an understanding of the culture and social context of the people who use it. For this reason, the process of translating from the national language into a sign language is complicated and requires the interpreter not only to know both languages, but also to be able to interpret and translate the meaning. Sign language interpreters must consider not only the literal meaning of words, but also their connotations and cultural context. It is also important to skilfully use gestures, facial expressions and body movements to convey the speaker's emotions and intentions [3].

Increasing equal opportunities and participation of deaf people in society is important, therefore the need to develop solutions aimed at reducing the social exclusion of deaf people is the result of growing social awareness and legal obligations regarding equal access to services and information for all citizens. For this reason, research and development of solutions for automatic translation of natural language into sign language are of great importance to deaf people. Creating new solutions that automatically convert spoken language into sign language has great potential in removing communication barriers and enabling full participation of deaf people in various areas of social and professional life.

Research into automatic translation of natural language into sign language requires the use of advanced technologies such as artificial intelligence, machine learning and natural language processing. As a result, the development of such solutions contributes to technological progress and is also used in other fields, such as machine translation or speech recognition. The most important thing is that scientific research and creating solutions for automatic translation of natural language into sign language have a direct impact on improving the quality of life of deaf people. Eliminating communication barriers and enabling full participation in society contributes to greater equality and social inclusion for this community.

The aim of this article is to present an overview of research on sign language translation and to identify links between research conducted in various areas related to this field. Through our work, we aim to provide readers with a comprehensive view of contemporary research related to sign language interpretation, addressing a variety of aspects, such as translation efficiency, quality of interpreting services, technological support, and social and cultural contexts. Our work focuses on identifying common points and interconnections between research conducted in various areas that, having an interdisciplinary nature, relate to sign language translation. By analyzing these relationships, the article aims to develop understanding of the sign language translation process and on the potential benefits and challenges of an interdisciplinary approach to research in this field.

Our key goal is to implement the project of developing a virtual human figure presenting the content of public ad-

ministration in Polish Sign Language. The project broadly aims to increase accessibility for deaf people – particularly those who use Polish Sign Language but do not understand Polish. It is a comprehensive solution in which it is necessary to prepare both a module for language translation and a corresponding avatar that is used to sign translated texts. To achieve this goal, it is necessary to familiarize yourself with the research and scientific and theoretical achievements in the field of sign language translation and their implications for translation practice. Although many of the analyzed studies are interdisciplinary in nature, one can distinguish the pursuit of scientists in specific directions. For this reason, we want to present our review of the work in the proposed research areas and encourage researchers to further research and development in the field of sign language interpretation. By identifying areas for further research and challenges, the article aims to stimulate conversations and innovations that will contribute to the continuous improvement of sign language services and the full participation of people with hearing impairments in society.

This article is organized as follows. The section I provides an introduction to the subject of this article. Section II provides an overview of related work on sign language interpretation methods. Section III describes a solution model that uses machine learning to automatically translate texts into Polish Sign Language. In the section IV, we present our proposed analysis of the literature review, where we indicate key research areas. In the sections VI, V and VII we present research into sign language translation broken down into the indicated areas. In the section IX, we present the results of identified links between research conducted in various areas. Finally, in the section X we conclude with general remarks about this work and indicate some directions for future research.

II. Related works

Traditional methods of obtaining information allow deaf people to become familiar with a very small percentage of digital information. In the context of the huge amount of material to be translated, it seems necessary to use semi-automatic and automatic tools to make at least some of it available in sign language on an ongoing basis [4]. Three basic barriers to automatic sign language translation have been distinguished, i.e. differences in modality, lack of a standard written form and a shortage of resources in the form of tools and technologies for translation as well as a limited number of sign language corpora [5]. In addition, the scope of sign language synthesis was defined by a detailed discussion of sign language dictionaries and repositories [6], [7]. A thorough review of the synthesis of sign language from the perspective of animation was also carried out, paying attention to the difference between the synthesis of single signs and the generation of full statements [7].

In some countries, public administrations are required to provide sign language interpretation for deaf people to enable them to fully enjoy public services. Translations are required to be available in places such as government offices, hospitals, schools and courts [8]. Public organizations must meet guidelines on the qualification and professionalism of sign language interpreters to ensure effective and accurate interpretation. The authors [9] focused on the criteria that public entities placed in virtual reality would have to meet, and pointed out that the appearance of avatars representing officials should be adequate to the situation of a fairly official nature. In [10], a framework of public values was developed that virtual advisors in offices should follow.

Many works indicate the interdisciplinary nature of the subject of sign language avatars and the great importance of non-manual signs, facial expressions and facial expressions, which is a great challenge for researchers dealing with the subject of sign language synthesis [11], [12]. The author [13] points to three interrelated threads, i.e. a linguistic approach to facial expressions that an avatar must have in order to convey a comprehensible message, computer graphics providing tools and technologies that are required to create avatars, and the third thread deals with the subject of sign language representation systems from the point of view of their ability to represent non-manual signs and facial expressions. The topic of non-manual signs, facial expressions and generating synthetic emotions was also addressed in works [3], [14]–[16]. Moreover, in [17], [18], a study of social trust in chat bots conducted was described. The study was based on theories of operators' trust in machines in industrial environments, showing that acceptance and trust can be related to the field in which the technology was introduced.

III. Project $Avatar2PJM$

The research is part of the $Avatar2PJM$ project (Project: Framework of an automatic translator into the Polish Sign Language using the avatar mechanism, The National Centre for Research and Development, GOSPOSTRATEG-IV/0002/2020). This project aims to develop a solution for translating speech from Polish into Polish Sign Language using avatar and artificial intelligence methods. The innovation of this solution lies in the inclusion of emotions and non-verbal elements in the visualisation of gestures.

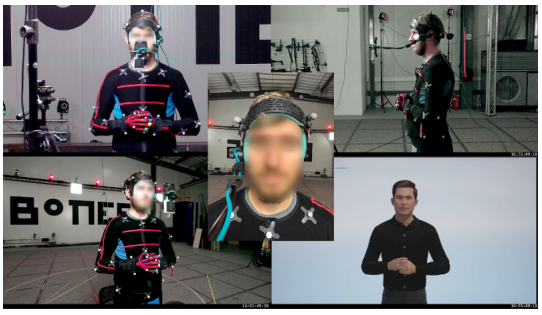

Fig. 1. MoCap recordings as part of the $Avatar2PJM$ project.

One of the key objectives of the project is to develop a method of translating Polish into Polish Sign Language using the avatar application control mechanism. A sign language avatar is a computer representation (animation) of linguistic

phenomena. With appropriate reference material recorded in video form, it is possible to animate any described speech. To this end, Motion Capture (MoCap) sessions were conducted, which is a technique for capturing the actor's three-dimensional movements (see Fig. 1). Used in computer games, the MoCap technique imitates the natural movements of objects or people in a very realistic way to achieve a natural effect. In the case of sign language avatars, MoCap makes it possible to copy sign language signs and increase the understanding of the communicated content, since, from the animator's perspective, spoken sign language signs consist of geometric positions and movements.

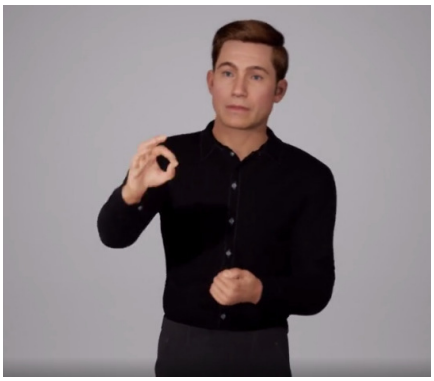

Fig. 2. Actual avatar prepared for testing the $Avatar2PJM$ project.

A sign language message consists of both sign language signs and various additional information, as what is physically expressed is the result of co-existing linguistic and extra-linguistic processes. In the process of creating computer-generated animations, the emotional context of the utterance is taken into account, as well as phenomena such as correct mouth movements or voiceless speech that occur during sign language communication. In particular, the sign language interpreter's facial expressions and the information they convey are important. Such elements are also important in the context of the data needed to develop the interpreting module. The material acquired during the MoCap session is used to feed the animation module and provide an input data set for the translation module based on machine learning methods. For this to be possible, it is necessary to subject the collection of recordings to an annotation process. The annotation process involves describing individual sign language sign elements at specific intervals. This includes sign units, lexical interpretations (lemmas, lexemes), as well as information concerning the non-manual elements of the sign. Since one of the key elements of annotation is the sign language interpreter's face, and this process is time-consuming, an attempt was made to explore the possibility of automatically recognising the interpreter's facial expressions. Automatic annotation would significantly improve and speed up the annotator's work. The article describes partial results of the research carried out in this field.

One of the expected outcomes of the project is pilot testing of selected online information services run by public administrations (the avatar used in the tests is presented in the Fig. 2). The widespread use of automatic translation mechanisms in public online systems is a constructive step towards improving the accessibility of digital public administration. In addition, the project team is investigating the professional potential of deaf people and their satisfaction with contact with public administration before and after the implementation of the virtual interpreter. This will identify the social and economic barriers that deaf people face in their contacts with the administration and in the labour market. The vocational potential of deaf people will also be explored, as well as methods of capturing data to maximise the effects of vocational activation. The results of the project will contribute to the sustainable elimination of barriers faced by users of Polish Sign Language.

IV. Proposed approach

When analyzing the current state of knowledge on the subject of sign language interpretation, one should pay attention to the interdisciplinarity of the subject of research, which combines various areas of knowledge in order to better understand this natural language of communication for the deaf. The interdisciplinarity of this research allows for a holistic approach to the issue of sign language translation. It requires collaboration between scientists and specialists in various fields to improve the translation process and develop new tools and strategies.

In order to provide a comprehensive view of contemporary research on sign language, we decided to analyze many scientific papers related to sign language translation, group them according to the nature of research, and then identify links between research conducted in different areas. To this end, we can identify three research areas related to sign language:

- the technological area where research focuses on developing and improving technological solutions related to sign language interpretation;
- the character animation area, where the proposed approaches relate to character animation for conveying information in sign language;
- the area of application, which presents solutions related to the use of automation in the field of providing information in sign language.

In the technological area, we want to classify works related to e.g. with translation into sign language, also in terms of the transition from the national language to the national sign language. In these works, researchers focus on developing innovative technological solutions for sign language translation. In this respect, classic methods can be distinguished, which include converting speech from the national language into sign language, often using motion capture techniques to generate animations. However, the development of artificial intelligence is also playing an increasingly important role, enabling the automatic translation of speech into sign language. In the technological area, research is focused on improving these methods and developing new tools and strategies that will improve the sign language translation process.

The character animation area focuses on ways to animate characters that convey information through sign language. Here too, motion capture techniques are often used to generate character animations that reflect flicker. It is also possible to create animations based on pre-recorded sequences performed by a lector. The aim of research in this area is to improve character animation techniques and search for new solutions that will allow even better transfer of information in sign language.

On the other hand, in the area of applications, research focuses on the use of automation in the transmission of information in sign language. Automation can be used in various contexts, for example in translation systems or online communication. The aim of the research is to improve these solutions so as to enable easier and more effective communication for deaf people using sign language.

In addition, there are many works related to with the analysis of accessibility [19], chaterbots [20], translations of sign languages [21] (e.g. from English (BSL) or American (ALS) to another sign language), or the development of applications related in some way to the implemented project [22]. Such a group in our research was named as other works and requires further analysis.

V. The technological area

The technological area is usually concerned with the translation of spoken language into sign language as input using text, sound or image. There are also studies on reverse translation, for example the solution described in [23], the system is able to recognize sign language poses and translate through avatars in the form of talking faces [24]. Many works also focus on the development of two-way communication by creating solutions that translate spoken languages into sign languages, and are able to recognize sign languages, as for example in works [8], [25], [26].

A. Recognition and translation of sign language into spoken languages

In the field of recognizing and translating sign language into spoken languages, we can distinguish the work [23] in which the authors proposed a solution for translating films with signers through a speaking avatar. This solution is able to generate videos with "talking faces" translating poses from sign language.

Another example is an AI-based novel approach to capturing and representing sign language [27]. A solution to the problem of unavailability of annotated sign language datasets is presented in the form of a crowdsourcing platform [28]. The authors [29] present an innovative approach to automatic sign language synthesis based on advances in the field of machine translation. A system has been proposed that is able to generate sign language videos from spoken language videos. Creating sequences of human poses is based on a combination of neural network-based machine translation (NMT) with motion graphs (MG). Kolejnym rozwiązaniem jest system rozpoznawania ruchu działający w czasie rzeczywistym z wykorzystaniem sygnału elektromiografii zaprezentowany w pracy [70]. Wyniki badań pokazały, że system może z dużą dokładnością rozpoznawać 20 znaczących i szeroko stosowanych ruchów ASL. Another solution is a real-time motion recognition system using the electromyography signal presented in [30]. Test results showed that the system could recognize 20 significant and widely used ASL movements with high accuracy.

B. Two-way communication

Recognition and translation of sign language into spoken languages and vice versa, i.e. two-way communication, is another important area of research related to sign language translation. Two-way communication is essential to ensure smooth interaction between deaf people using sign language and hearing people using spoken language.

The task of the European project [8] is to develop technology for automatic translation of sign languages into spoken languages and vice versa. The solution will be provided in the form of a mobile application for translation and communication. It focuses on several languages, i.e. English, Irish, Dutch and Spanish. In addition, the EXTOL project [25] was developed, which aims to develop the world's first system for translating British Sign Language into English and a functional machine translation system for any sign language. On the other hand, in [31] an automatic system for registering deaf patients was proposed, including a workstation with a computer, an RGB camera and a depth sensor (Kinect). Work related to sign language also applies to translations into Chinese. The proposed solution [26] is a framework-based framework for recognizing and generating Chinese Sign Language based on a recursive neural network. The algorithm has high accuracy in recognizing real and synthetic data, with reduced execution time.

C. Translation of spoken languages into sign languages

An important process among the aforementioned translations is the translation of spoken languages such as text, voice or film into sign languages. This is an important area of research and technological development that aims to facilitate communication between hearing people and deaf people who use sign language. This area includes paper [32] in which an Arabic sign language dictionary was developed using the HamNoSys notation and eSIGN editing software. Also presented is the SIGML sign language, where characters are presented using a 3D avatar, 3000 characters. The Mexican Sign Language avatar presented by the authors [33] was created based on a combination of natural language processing (NLP) techniques with the use of programming engines (Unity) to create animation. Using the structured language model of AZee, Paul's Avatar [34] was created, which is a hybrid system animated mainly with hand-made keyframes, and Kazoo's virtual avatar [35], which generates content from French to sign language.

On the basis of the results available in related literature, an analysis and evaluation of the Portuguese Sign Language (LIBRAS) translation system developed as part of the project

was carried out in the context of generating signs and sentences considered ungrammatical by the Deaf community [36]. ProDeaf was developed as computer software for Portuguese Sign Language [4]. Translation takes place both from voice and from text to sign language. However, the proposed application is focused on one-way communication and is not able to translate sign language into text or sound.

On the other hand, for Hindi, a system was proposed that translates English text into Indian Sign Language (ISL) via a 3D avatar [37]. The basic component is an ISL parser that allows parsing sentences based on ISL grammar rules. The system does not use previously saved photos and videos, it displays representations of sentences and words in real time. The Indian Sign Language Dictionary [38], which is bilingual for both English and Hindi, uses the Hamburg notation system and markup language SIGML and the Web Graphics Library (WebGL) to animate 3D avatars. The presented dictionary has 2000 English words and 3286 Hindi words with 110 example sentences.

VI. The character animation area

Major sign language research focuses on the recognition and production of sign languages, as well as the improvement of sign language systems and tools. Research is focused on the development of advanced systems and tools that enable the generation of sign language animations [34], [39]. In this context, researchers are developing software that allows the creation of fluid gestures, facial expressions and body movements characteristic of sign language. For more authentic sign language animations, research is focused on developing motion capture techniques. Researchers are developing techniques that enable realistic facial expressions and emotional expression in sign language animation [40]. Improving the quality of animation and adding facial expressions contributes to better communication and understanding of the information conveyed [41].

A. Systems and tools in sign language animation

One of the proposed tools is Kazoo's virtual avatar [35], which generates content from French to sign language. This project offers the possibility of automatically animating a virtual avatar and content synthesis based on an abstract representation of the author's language model AZee. Paul's English Sign Language avatar was created using the AZee structured language model [34]. Developed at DePaul University by a team of scientists who are working on the avatar. The main goal is to create an avatar that would translate English to ASL in real time.

An interesting solution is a system that allows adding sign language translations in the form of a 3D avatar to digital mathematical educational materials [39]. Operation and construction of ASL System, which consists of 3 basic components: supporting the 3D model, supporting animations, supporting rendering. The SignGAN system [40] on the other hand, is a model for sign language production, a neural network-based translator between text and a synthesized skeletal pose, creating photorealistic sign language videos directly from spoken language. The proposed solution reduces the problems associated with motion blur.

B. Motion Capture Techniques for Sign Language Animation

Advanced motion capture, image processing, and virtualization techniques are often used to create a 3D avatar. An example is the avatar, which acts as a teacher of quite specific concepts in the field of electrical engineering in sign language [42] and the aforementioned Kazoo avatar [35] or Paul's avatar [34].

The key barriers to sign language generation, in particular differences in modality, lack of a standard written form and insufficient resources, are presented in paper [5]. The state of the art and challenges in presenting non-manual signs in avatar animation were also presented from the point of view of three areas, i.e. linguistic approach to facial expressions; Computer Graphics; sign language representation systems [13]. Solving the problem [27] of unavailability of annotated sign language datasets in the form of a crowdsourcing platform has been presented as a novel approach to capturing and representing sign language.

C. Efforts to improve the quality and realism as well as facial expression in sign language animation

Actions to improve the quality and realism of sign language animation are very important in order to better understand the information conveyed. For this reason, a new method [43] based on machine learning was proposed to automatically calculate three key values: selecting the location for inserting pauses, setting the differential speed of individual words, and setting the duration of pauses. In addition, in the years 2006 - 2014, models were worked on that combine language phenomena with specific facial movements in order to generate animations, and an infrastructure for animation synthesis using MPEG-4 facial animation parameters was developed [15].

On the basis of a review of existing lighting models and current progress and research efforts in the field of facial expression and facial expressions, an innovative technique was proposed [11] modifying the classic computer graphics techniques, which, according to the author, is the most efficient combination to present the smallest details. In addition to the automatic generation of complex facial expressions in 3D avatars, a new parametric model of facial expression synthesis using 3D avatars has been proposed [14].

VII. The area of application

The use of translation from the national language into sign language is especially important in situations where communication is necessary to understand and express thoughts, such as business meetings, school activities or conversations with a doctor. Thanks to appropriate translation, deaf people can actively participate in discussions, make decisions and express their views. The development of technologies, such as mobile applications or interactive screens, opens up new possibilities

in the field of translation from the national language into the sign language. These innovations facilitate a faster and more precise translation process, thus enabling more effective communication between deaf and hearing people [44].

An important area of application for sign language avatars seems to be all issues related to meeting basic needs and ensuring proper functioning in various spheres of public and social life. Avatars should be used wherever access to information is crucial and it is not possible to employ a professional sign language interpreter. In particular, applications in the field of education, medicine and security and transport can be distinguished here.

A. Education Application

Automatic translation of natural language into sign language has the potential to improve the quality of education for deaf people. Access to translation tools enabling understanding of the content taught at school is invaluable for the intellectual and educational development of this group of people. The Mexican Sign Language Avatar, as a mobile application via a cloud server using NLP and automatic translation, will present limited content from a 4th grade primary Mexican history textbook in sign language [33].

In order to teach mathematics, an e-learning system was developed that was developed for Arab deaf sign language students using an Arabic Sign Language avatar [45], as well as a system for adding sign language translations in the form of a 3D avatar to digital math education materials [39]. A system facilitating independent learning of English Sign Language [46] has also been developed, in which the user has a graphical interface at his/her disposal. This system is based on a neural network that classifies signs flashed in the hand alphabet, recorded with a webcam.

Many efforts have been made in the field of education, e.g. in [47] a Turkish project was described, which presented the benefits of using 3D Avatar in the process of educating deaf children. For the experiment, an avatar was created and a test was performed using it to compare the educational effectiveness of the avatar with text-based learning tools. The results indicated that avatar-based tutoring was more effective in assessing a child's knowledge of certain words in sign language. In the field of education, dictionaries in English [34], Irish [48], Arabic [32] and Indian [37], [38] as well as Portuguese [42] dictionaries may also be considered.

B. Medical Application

The period of the pandemic significantly verified the accessibility of deaf people to medical care. Dutch researchers in [49], [50] studied the potential of automatic translation of text into sign language. Based on consultations with medical professionals, they built a corpus of the most frequently used expressions when diagnosing COVID. SIGML representation and JASignin avatar were used. Attention was drawn to the advantage of avatar over video translation in terms of flexibility and scaling. A definitely lower level of realism and difficulty of understanding was considered a disadvantage.

In a situation where physical well-being is at stake, patients are likely to feel more comfortable watching a human film than an animated avatar [51]. It was also found that users have greater acceptance of virtual advisors operating in general areas, e.g. answering questions in the field of waste management. However, in the case of more personal topics, e.g. parental support, they feel anxiety and distrust when the advisor is not a human but a virtual assistan [52], [53].

C. Security and transportation applications

In the area of ensuring safety, one of the examples of application can be the paper [54], which dealt with the subject of messages about disasters. The authors focus on voice notations that are widely used to transcribe video sequences in sign language. In the first steps, the authors created a corpus for disaster messages in Indian language to be presented by an avatar. In terms of character animation, two methods of Motion Capture and Video Tracing were investigated, for reasons of cost, it was decided to use Video Tracing, which creates 2D avatars. An avatar was created based on the video, the process of animating a 3D avatar based on a 2D video required a lot of effort and a lot of manual tweaking. The final generated corpus contained about 4,000 words on the subject of disasters and about 600 sentences. Several solutions have been identified to ensure smooth avatar movements during translation. However, collecting data on emotional expression and facial expressions remained a challenge during the work. Another example is the avatar of a machine translation system under development, built to translate Swiss Federal Railways' messages in real time [55]. The JASigning software was used to generate the avatar animations.

D. Public administration

Public administration is increasingly showing interest in AI technologies and their implementation. There are numerous publications showing all the research towards the acceptance of modern technologies and the way they are implemented, among others in offices [56], [57]. All actions taken in this direction and their results can be partly related to the implementation of sign language avatar technology. Sign language avatars should primarily be focused on ensuring accessibility to services, but they must also meet all other criteria and be appropriately adapted to the specific area of public administration [58].

For this purpose, a study of trust in virtual advisors in public administration was conducted [17] and the possibilities of using artificial intelligence techniques in public administration were discussed [59]. The methods of using modern technologies in employee training in the context of occupational health and safety were shown [60], and the advantages and potential threats in the use of virtual advisors in public administration were presented [61]. In the research on the introduction of virtual reality to public administration, the criteria that must be met were set, where an example is the appearance of avatars in offices [62], which should have a fairly official character [9], and a framework for public values was developed, which

should include chat bots in public administration with examples of achievement [10]. In addition, research was conducted on the impact of implementing modern technologies in public administration in the context of changes in the relationship between employees and their tools, as well as changes in the ways of organizing work in the public sector [63].

The practical use of avatars was also reflected in the example of using avatars in libraries. Paper [64] presents the opportunities and possibilities of using spoken language in the avatar library. For the purpose of simulating crisis situations, the multi-agent multi-user architecture was used, which allows the use of virtual cities as environments for simulations with participants in the form of avatars [65].

E. General use

Works that are not strictly related to the application of research in one area can be indicated here as general application. The proposed solutions are often universal, and small transformations or refinements of parameters to a specific problem indicate their general applications. In the case of general applications, practical projects are most often created, such as applications, systems or other tools, but we also present here theoretical analyzes in the form of literature and systems reviews. An example of general applications may be a web application for generating sign language using the Kazoo virtual avatar [35]. This project is in progress, and the current version offers the ability to automatically animate a virtual avatar and synthesize content based on an abstract representation of the proprietary AZee language model. The same applies to the PE2LGP Animator tool [66], which was created as part of a wider project on the translation of Portuguese Sign Language. The tool allows users with no technical knowledge or animation experience to create LGP character animations for avatars using simple frame-by-frame poses [67].

Another project is a novel machine translation model [68] that translates English sentences into the Pakistani Sign Language equivalent. The system consists of an NLP pipeline and an external video rendering service for translated words based on avatars. In the aforementioned European Project [8], the task was to develop a technology for automatic translation of sign languages into spoken languages and vice versa. The solution will be provided in the form of a mobile application for translation and communication. It focuses on English Irish, Dutch, Spanish language. The Austrian project SIMAX [69] is being implemented as a semi-automatic system for interpreting into sign language. It is one of the most comprehensive systems and consists of several highly advanced ICT technologies. However, The benefits of using synthetic characters from the HamNoSys/SiGML notation instead of working with advanced and expensive motion capture technology were presented on the example of the eSIGN project [70]. It was a development of the ViSiCAST system, which was created as a new project.

VIII. THE OTHER WORKS

In some of the analyzed works, it was not possible to indicate one main area of research, therefore we defined a group of other works. Our goal is to show that although much research is focused on one area, sign language research is interdisciplinary. Therefore, in this section we analyze papers providing an overview of solutions to various problems in the field of sign language interpretation.

The authors [36] developed a translation system for Portuguese Sign Language (LIBRAS) and presented research in the context of generating signs and sentences considered ungrammatical by the Deaf community [71]. However, in [67], various methods for finding the meaning of an unknown word in American Sign Language (ASL) were investigated. An overview of currently existing translation systems with their advantages and disadvantages as well as the approach they use is discussed in [4]. A new approach to the construction of sign languages has also been proposed, which significantly increases accuracy in translation. A systematic review of the literature [6] on the synthesis of sign language was carried out, in which dictionaries and repositories of sign languages were discussed in detail, emphasizing the importance of sign notation; translation systems and application areas [72]. Similarly, the authors of the paper [7] reviewed the synthesis of sign language from the perspective of animation, noting the difference between the synthesis of single signs and the generation of complete statements.

A review of existing sign language avatars in the context of details and facial expressions is presented in [11], [41]. An overview of modern techniques for generating facial expressions from the last 15 years was developed, based on 5 examples of avatar use in projects: HamNoSys-based, VComD, DePaul, SignCom, ClustLexical [16]. However, the authors [44] conducted research on the intelligibility of sign language avatars, in terms of methodology, it was proposed to combine a focus group with online research. In addition to determining the key aspects that the deaf community pays attention to in the avatar, it has been shown that the very conduct of research among the deaf community affects their positive perception of avatars [62]. The authors [73] developed a technique for automatically adding realism to animation without the need to manually animate details, and also identified issues related to avatar optimization that can reduce real-time rendering costs. It was also examined to what extent synthetically generated animations are understandable by the deaf community both in the form of skeletal visualizations and generated films [74]. The results show that the deaf community prefers synthetically realistic generated animations to skeletal visualization, it was pointed out that automatic methods of synthesis are not effective enough, the respondents had difficulties in recognizing some signs [75], [76].

Research [3], [12] focused on Irish Sign Language, where the impact of avatar facial expressions on better understanding and acceptance by the deaf community was analyzed and assessed. The reception of avatars' utterances with facial

expressions enriched with 7 commonly accepted emotions was compared with the avatars' basic utterances. The results showed that the differences in understanding the content are small. In [27], however, the problem of unavailability of annotated sign language datasets in the form of a crowdsourcing platform was solved.

New challenges for sign language processing have also emerged, based on a discussion of the interdisciplinary nature and multidimensional approach based on Italian Sign Language [77], [78]. An overview of the most modern methods of interception, recognition, translation and representation in sign language, with an indication of their advantages and limitations, was made in [79]. In contrast, the authors [80] analyzed recent advances in the fields of deep learning recognition and production of sign language. The advantages, limitations and future directions for research are discussed, and key barriers to sign language generation such as differences in modality, lack of a standard written form, insufficient resources are presented [5].

IX. Results of literature review analysis

As part of the review of the literature on research on sign language, nearly several hundred scientific papers were reviewed. However, several dozen most closely related to the scope of work were selected for this study. A significant part of the works has been presented in the sections VI, V and VII, where they have been grouped according to the areas (character animation area, technological area and applications), with the exception that some works concern several areas. Such a situation is additionally presented in the figure 3 (together with other works), where all articles are in appropriate groups – it is possible to notice the permeability of works between the analyzed scopes of works.

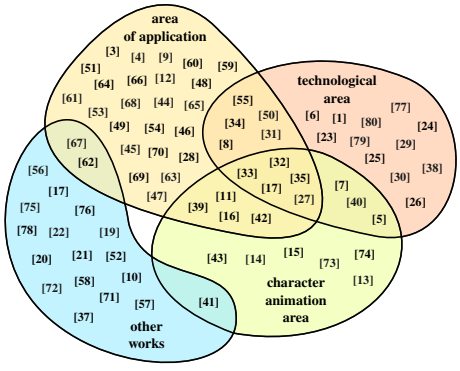

Fig. 3. Relationships between publications from different areas, based on the analyzed literature.

Over the dozens of analyzed works, it can be clearly seen that many of them concern only one area, but there are frequent connections between the application and technology or character animation. This means that there is a need to carry out scientific research combining the indicated areas.

Figure 4 presents boxplots for the number of publications by year and by area. It shows the current research related to the analyzed topic. As can be seen, the first articles were published in the years 2005 – 2008, since then the number of publications on sign language animation has increased significantly. The first quantile in the area related to animation and application is 2015, which is also a period of growth in publications in which there is a combination of sign language with technological possibilities. The median for most of the analyzed publications is 2019-2020. This shows that the analyzed subject matter is currently a very popular issue of research, application and development.

The observations resulting from the analysis of the drawing 3 also allow to justify the division adopted in this review of the current state of knowledge. It is important to thoroughly research both character animation and sign language applications, including - above all - from a technological point of view. The presentation of the multitude of works that have been analyzed requires an appropriate methodological approach. Hence the appropriate, original grouping of all works. On the other hand, the presentation of statistics related to publication dates (see fig. 4) is related to emphasizing the needs related to the discussed topic and its topicality. The needs are already visible on the example of similar works, which are related to e.g. with the analysis of accessibility for people with special needs and appear already in 2005. On the other hand, the topicality is indicated by a clear shift of the median and the third quantile to around 2020-2021 - primarily in the area of technology and character animation.

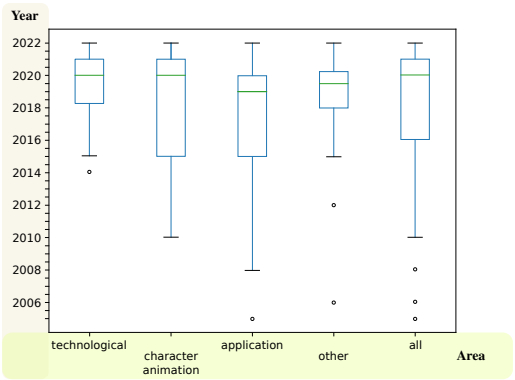

Fig. 4. Boxplots for the publication dates of the analyzed papers related to the subject of the project, in relation to the areas

X. Conclusions

This article focuses on the importance of national language to sign language translation as an important area of research and practice to enable communication between people with hearing impairments and the hearing community. The most important research on sign language interpretation conducted in various fields is reviewed. The article presents the latest scientific and theoretical achievements that contribute to a better understanding of this subject and the improvement of the quality of translation services.

The main aim of the article is to indicate the outstanding areas of interdisciplinary research related to sign language translation and to identify the links between these studies conducted in various fields. The authors try to broaden the knowledge and awareness of sign language interpretation, as well as identify areas that require further research and development.

The conclusions of the article aim to facilitate the improvement of interpretation practices and to promote further research and innovation in the field of sign language translation. This work is important to the hearing impaired community as it provides a better understanding of the communication needs of these people and inspires further efforts to improve the accessibility and effectiveness of sign language interpretation.

In conclusion, the subject of sign language animation is still quite a new and quite complicated field, because it combines many scientific disciplines, from linguistics to machine translation based on neural networks and advanced computer graphics. Today, professionals are collaborating and exploring many areas to develop acceptable and useful solutions to support deaf communities. Despite the great technological progress, the majority of works still discuss numerous challenges and barriers that must be faced in order to ensure full access to information that is so important for deaf people today. Ultimately, improving the quality of sign language interpretation services will contribute to strengthening the social inclusion and equality of people with hearing impairments, ensuring their full access to information and services in all spheres of life.

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REFERENCES

[1] S. K. Liddell, "American sign language syntax," in *American Sign Language Syntax*. De Gruyter Mouton, 2021.

[2] A. Patil, A. Kulkarni, H. Yesane, M. Sadani, and P. Satav, "Literature survey: sign language recognition using gesture recognition and natural language processing," *Data Management, Analytics and Innovation: Proceedings of ICDMAI 2021, Volume 1*, pp. 197–210, 2021.

[3] R. Smith and B. Nolan, "Manual evaluation of synthesised sign language avatars," in *Proceedings of the 15th international ACM SIGACCESS conference on computers and accessibility*, 2013, pp. 1–2.

[4] K. Shah, S. Rathi, R. Shetty, and K. Mistry, "A comprehensive review on text to indian sign language translation systems," *Smart Trends in Computing and Communications: Proceedings of SmartCom 2021*, pp. 505–513, 2022.

[5] R. Wolfe, "Sign language translation and avatar technology," *Machine Translation*, vol. 35, no. 3, pp. 301–304, 2021.

[6] U. Farooq, M. S. M. Rahim, N. Sabir, A. Hussain, and A. Abid, "Advances in machine translation for sign language: approaches, limitations, and challenges," *Neural Computing and Applications*, vol. 33, no. 21, pp. 14 357–14 399, 2021.

[7] L. Naert, C. Larboulette, and S. Gibet, "A survey on the animation of signing avatars: From sign representation to utterance synthesis," *Computers & Graphics*, vol. 92, pp. 76–98, 2020.

[8] H. Saggion, D. Shterionov, G. Labaka, T. Van de Cruys, V. Vandeghinste, and J. Blat, "Signon: Bridging the gap between sign and spoken languages," in *Alkorta J, Gonzalez-Dios I, Atutxa A, Gojenola K, Martínez-Cámara E, Rodrigo A, Martínez P, editors. Proceedings of the Annual Conference of the Spanish Association for Natural Language Processing: Projects and Demonstrations (SEPLN-PD 2021) co-located with the Conference of the Spanish Society for Natural Language Processing (SEPLN 2021); 2021 Sep 21-24; Málaga, Spain. Aachen: CEUR Workshop Proceedings; 2021. p. 21-5.* CEUR Workshop Proceedings, 2021.

[9] I. Tozsa, "Virtual reality and public administration," *Transylvanian Review of Administrative Sciences*, vol. 9, no. 38, pp. 202–212, 2013.

[10] T. Makasi, A. Nili, K. Desouza, and M. Tate, "Chatbot-mediated public service delivery: A public service value-based framework," *First Monday*, 2020.

[11] R. Johnson, "Towards enhanced visual clarity of sign language avatars through recreation of fine facial detail," *Machine Translation*, vol. 35, no. 3, pp. 431–445, 2021.

[12] R. G. Smith and B. Nolan, "Emotional facial expressions in synthesised sign language avatars: a manual evaluation," *Universal Access in the Information Society*, vol. 15, pp. 567–576, 2016.

[13] R. Wolfe, J. McDonald, R. Johnson, R. Moncrief, A. Alexander, B. Sturr, S. Klinghoffer, F. Conneely, M. Saenz, and S. Choudhry, "State of the art and future challenges of the portrayal of facial nonmanual signals by signing avatar," in *Universal Access in Human-Computer Interaction. Design Methods and User Experience: 15th International Conference, UAHCI 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part I.* Springer, 2021, pp. 639–655.

[14] D. A. Gonçalves, M. C. C. Baranauskas, J. C. dos Reis, and E. Todt, "Facial expressions animation in sign language based on spatio-temporal centroid." in *ICEIS (2)*, 2020, pp. 463–475.

[15] M. Huenerfauth, "Learning to generate understandable animations of american sign language," 2014.

[16] H. Kacorri, "Tr-2015001: A survey and critique of facial expression synthesis in sign language animation," 2015.

[17] N. Aoki, "An experimental study of public trust in ai chatbots in the public sector," *Government Information Quarterly*, vol. 37, no. 4, p. 101490, 2020.

[18] C. Van Noordt and G. Misuraca, "New wine in old bottles: Chatbots in government: Exploring the transformative impact of chatbots in public service delivery," in *Electronic Participation: 11th IFIP WG 8.5 International Conference, ePart 2019, San Benedetto Del Tronto, Italy, September 2–4, 2019, Proceedings 11.* Springer, 2019, pp. 49–59.

[19] C. Geraci, "Language policy and planning: The case of italian sign language," *Sign Language Studies*, vol. 12, no. 4, pp. 494–518, 2012.

[20] V. Hristidis, "Chatbot technologies and challenges," in *2018 First International Conference on Artificial Intelligence for Industries (AI4I)*. IEEE, 2018, pp. 126–126.

[21] N. K. Kahlon and W. Singh, "Machine translation from text to sign language: a systematic review," *Universal Access in the Information Society*, vol. 22, no. 1, pp. 1–35, 2023.

[22] U. Farooq, M. S. M. Rahim, N. S. Khan, S. Rasheed, and A. Abid, "A crowdsourcing-based framework for the development and validation of machine readable parallel corpus for sign languages," *IEEE Access*, vol. 9, pp. 91 788–91 806, 2021.

[23] S. Mazumder, R. Mukhopadhyay, V. P. Namboodiri, and C. Jawahar, "Translating sign language videos to talking faces," in *Proceedings of the Twelfth Indian Conference on Computer Vision, Graphics and Image Processing*, 2021, pp. 1–10.

[24] N. S. Khan, A. Abid, K. Abid, U. Farooq, M. S. Farooq, and H. Jameel, "Speak pakistan: Challenges in developing pakistan sign language using information technology," *South Asian Studies*, vol. 30, no. 2, 2020.

[25] K. Cormier, N. Fox, B. Woll, A. Zisserman, N. C. Camgöz, and R. Bowden, "Extol: Automatic recognition of british sign language using the bsl corpus," in *Proceedings of 6th Workshop on Sign Language Translation and Avatar Technology (SLTAT) 2019*. Universitat Hamburg, 2019.

[26] Q. Xiao, M. Qin, and Y. Yin, "Skeleton-based chinese sign language recognition and generation for bidirectional communication between deaf and hearing people," *Neural networks*, vol. 125, pp. 41–55, 2020.

[27] K. Stefanidis, D. Konstantinidis, A. Kalvourtzis, K. Dimitropoulos, and P. Daras, "3d technologies and applications in sign language," *Recent advances in 3D imaging, modeling, and reconstruction*, pp. 50–78, 2020.

[28] A. Soudi, K. Van Laerhoven, and E. Bou-Souf, "Africasign–a crowdsourcing platform for the documentation of stem vocabulary in african sign languages," in *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 2019, pp. 658–660.

[29] S. Stoll, N. C. Camgoz, S. Hadfield, and R. Bowden, "Text2sign: towards sign language production using neural machine translation and generative adversarial networks," *International Journal of Computer Vision*, vol. 128, no. 4, pp. 891–908, 2020.

[30] S. Tateno, H. Liu, and J. Ou, "Development of sign language motion recognition system for hearing-impaired people using electromyography signal," *Sensors*, vol. 20, no. 20, p. 5807, 2020.

[31] D. Szulc, J. Gałka, M. Másior, F. Malawski, T. J. Wilczyński, and K. Wróbel, "Studies on machine processing of sign language in the context of deaf support. application in health care–interactive service system for the deaf."

[32] A. H. Aliwy and A. A. Ahmed, "Development of arabic sign language dictionary using 3d avatar technologies," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 609–616, 2021.

[33] F. Barrera Melchor, J. C. Alcibar Palacios, O. Pichardo-Lagunas, and B. Martinez-Seis, "Speech to mexican sign language for learning with an avatar," in *Advances in Computational Intelligence: 19th Mexican International Conference on Artificial Intelligence, MICAI 2020, Mexico City, Mexico, October 12–17, 2020, Proceedings, Part II 19*. Springer, 2020, pp. 179–192.

[34] M. Filhol and J. C. McDonald, "Extending the azee-paula shortcuts to enable natural proform synthesis," in *sign-lang@ LREC 2018*. European Language Resources Association (ELRA), 2018, pp. 45–52.

[35] A. Braffort, M. Filhol, M. Delorme, L. Bolot, A. Choisier, and C. Verrecchia, "Kazoo: a sign language generation platform based on production rules," *Universal Access in the Information Society*, vol. 15, pp. 541–550, 2016.

[36] L. S. García, T. Felipe, A. Guedes, D. R. Antunes, C. E. Iatskiu, E. Todt, J. Bueno, D. d. F. Trindade, D. Gonçalves, R. Canteri *et al.*, "Deaf inclusion through brazilian sign language: A computational architecture supporting artifacts and interactive applications and tools," in *Universal Access in Human-Computer Interaction. Access to Media, Learning and Assistive Environments: 15th International Conference, UAHCI 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part II*. Springer, 2021, pp. 167–185.

[37] P. Kumar and S. Kaur, "Sign language generation system based on indian sign language grammar," *ACM Transactions on Asian and Low-Resource Language Information Processing (TALLIP)*, vol. 19, no. 4, pp. 1–26, 2020.

[38] P. Kumar, S. Kaur *et al.*, "Online multilingual dictionary using hamburg notation for avatar-based indian sign language generation system," *International Journal of Cognitive and Language Sciences*, vol. 12, no. 8, pp. 1117–1124, 2018.

[39] K. Hayward, N. Adamo-Villani, and J. Lestina, "A computer animation system for creating deaf-accessible math and science curriculum materials." in *Eurographics (Education Papers)*, 2010, pp. 1–8.

[40] B. Saunders, N. C. Camgoz, and R. Bowden, "Everybody sign now: Translating spoken language to photo realistic sign language video," *arXiv preprint arXiv:2011.09846*, 2020.

[41] P. A. Angga, W. E. Fachri, A. Elevanita, R. D. Agushinta *et al.*, "Design of chatbot with 3d avatar, voice interface, and facial expression," in *2015 international conference on science in information technology (ICSITech)*. IEEE, 2015, pp. 326–330.

[42] T. Lima, M. S. Rocha, T. A. Santos, A. Benetti, E. Soares, and H. S. de Oliveira, "Innovation in learning–the use of avatar for sign language," in *Human-Computer Interaction. Applications and Services: 15th International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013, Proceedings, Part II 15*. Springer, 2013, pp. 428–433.

[43] S. Al-Khazraji, L. Berke, S. Kafle, P. Yeung, and M. Huenerfauth, "Modeling the speed and timing of american sign language to generate realistic animations," in *Proceedings of the 20th international ACM SIGACCESS conference on computers and accessibility*, 2018, pp. 259–270.

[44] M. Kipp, Q. Nguyen, A. Heloir, and S. Matthes, "Assessing the deaf user perspective on sign language avatars," in *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*, 2011, pp. 107–114.

[45] S. M. Shohieb, "A gamified e-learning framework for teaching mathematics to arab deaf students: Supporting an acting arabic sign language avatar," *Ubiquitous Learning: An International Journal*, vol. 12, no. 1, pp. 55–70, 2019.

[46] R. Rajendran and S. T. Ramachandran, "Finger spelled signs in sign language recognition using deep convolutional neural network," *International Journal of Research in Engineering, Science and Management*, vol. 4, no. 6, pp. 249–253, 2021.

[47] R. Yorganci, A. A. Kindiroglu, and H. Kose, "Avatar-based sign language training interface for primary school education," in *Workshop: Graphical and Robotic Embodied Agents for Therapeutic Systems*, 2016.

[48] L. C. Galea and A. F. Smeaton, "Recognising irish sign language using electromyography," in *2019 International Conference on Content-Based Multimedia Indexing (CBMI)*. IEEE, 2019, pp. 1–4.

[49] F. Roelofsen, L. Esselink, S. Mende-Gillings, M. De Meulder, N. Sijm, and A. Smeijers, "Online evaluation of text-to-sign translation by deaf end users: Some methodological recommendations (short paper)," in *Proceedings of the 1st International Workshop on Automatic Translation for Signed and Spoken Languages (AT4SSL)*, 2021, pp. 82–87.

[50] F. Roelofsen, L. Esselink, S. Mende-Gillings, and A. Smeijers, "Sign language translation in a healthcare setting," in *Proceedings of the Translation and Interpreting Technology Online Conference*, 2021, pp. 110–124.

[51] P. Bouillon, B. David, I. Strasly, and H. Spechbach, "A speech translation system for medical dialogue in sign language—questionnaire on user perspective of videos and the use of avatar technology," in *3rd Swiss Conference on Barrier-free Communication (BfC 2020)*, 2021, p. 46.

[52] R. De Maria Marchiano, G. Di Sante, G. Piro, C. Carbone, G. Tortora, L. Boldrini, A. Pietragalla, G. Daniele, M. Tredicine, A. Cesario *et al.*, "Translational research in the era of precision medicine: Where we are and where we will go," *Journal of Personalized Medicine*, vol. 11, no. 3, p. 216, 2021.

[53] D. Kruk, D. Mętel, Ł. Gawęda, and A. Cechnicki, "Implementation of virtual reality (vr) in diagnostics and therapy of nonaffective psychoses." *Psychiatria Polska*, vol. 54, no. 5, pp. 951–975, 2020.

[54] P. M. Martin, S. Belhe, S. Mudliar, M. Kulkarni, and S. Sahasrabudhe, "An indian sign language (isl) corpus of the domain disaster message using avatar," in *Proceedings of the third international symposium in sign language translations and technology (SLTAT-2013)*, 2013, pp. 1–4.

[55] S. Ebling and J. Glauert, "Building a swiss german sign language avatar with jasigning and evaluating it among the deaf community," *Universal Access in the Information Society*, vol. 15, pp. 577–587, 2016.

[56] A. Androutsopoulou, N. Karacapilidis, E. Loukis, and Y. Charalabidis, "Transforming the communication between citizens and government through ai-guided chatbots," *Government information quarterly*, vol. 36, no. 2, pp. 358–367, 2019.

[57] Y. Wang, N. Zhang, and X. Zhao, "Understanding the determinants in the different government ai adoption stages: Evidence of local government chatbots in china," *Social Science Computer Review*, vol. 40, no. 2, pp. 534–554, 2022.

[58] A. Lommatzsch, "A next generation chatbot-framework for the public administration," in *Innovations for Community Services: 18th International Conference, I4CS 2018, Žilina, Slovakia, June 18-20, 2018, Proceedings*. Springer, 2018, pp. 127–141.

[59] P. Henman, "Improving public services using artificial intelligence: possibilities, pitfalls, governance," *Asia Pacific Journal of Public Administration*, vol. 42, no. 4, pp. 209–221, 2020.

[60] A. Grabowski, "Wykorzystanie współczesnych technik rzeczywistości wirtualnej i rozszerzonej do szkolenia pracowników," *Bezpieczeństwo pracy: nauka i praktyka*, no. 4, pp. 18–21, 2012.

[61] B. Kopka, "Theoretical aspects of using virtual advisors in public administration."

[62] S. Pauser and U. Wagner, "Judging a book by its cover: Assessing the comprehensibility and perceived appearance of sign language avatars."

[63] T. M. Vogl, C. Seidelin, B. Ganesh, and J. Bright, "Smart technology and the emergence of algorithmic bureaucracy: Artificial intelligence in uk local authorities," *Public Administration Review*, vol. 80, no. 6, pp. 946–961, 2020.

[64] B. Jaskowska, "Nie wiesz? zapytaj awatara: wirtualny doradca w bibliotece," in *Biblioteka-klucz do sukcesu użytkowników (ePublikacje Instytutu Informacji Naukowej i Bibliotekoznawstwa, nr 5)*. Instytut Informacji Naukowej i Bibliotekoznawstwa, Uniwersytet Jagielloński, 2008, pp. 104–110.

[65] H. Nakanishi, S. Koizumi, and T. Ishida, "Virtual cities for real-world crisis management," in *Digital Cities III. Information Technologies for Social Capital: Cross-cultural Perspectives: Third International Digital Cities Workshop, Amsterdam, The Netherlands, September 18-19, 2003. Revised Selected Papers 3*. Springer, 2005, pp. 204–216.

[66] P. Cabral, M. Gonçalves, H. Nicolau, L. Coheur, and R. Santos, "Pe2lgp animator: A tool to animate a portuguese sign language avatar," in *Proceedings of the LREC2020 9th Workshop on the Representation and Processing of Sign Languages: Sign Language Resources in the Service of the Language Community, Technological Challenges and Application Perspectives*, 2020, pp. 33–38.

[67] O. Alonzo, A. Glasser, and M. Huenerfauth, "Effect of automatic sign recognition performance on the usability of video-based search interfaces for sign language dictionaries," in *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 2019, pp. 56–67.

[68] N. S. Khan, A. Abid, and K. Abid, "A novel natural language processing (nlp)–based machine translation model for english to pakistan sign language translation," *Cognitive Computation*, vol. 12, pp. 748–765, 2020.

[69] G. Tschare, "The sign language avatar project. innovative practice 2016," 2016.

[70] R. San-Segundo, R. Barra, L. D'haro, J. M. Montero, R. Córdoba, and J. Ferreiros, "A spanish speech to sign language translation system for assisting deaf-mute people," in *Ninth International Conference on Spoken Language Processing*, 2006.

[71] A. Pardasani, A. K. Sharma, S. Banerjee, V. Garg, and D. S. Roy, "Enhancing the ability to communicate by synthesizing american sign language using image recognition in a chatbot for differently abled," in *2018 7th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO)*. IEEE, 2018, pp. 529–532.

[72] A. Kizabekova and V. Chernyshenko, "E-government avatar-based modeling and development," in *Avatar-Based Control, Estimation, Communications, and Development of Neuron Multi-Functional Technology Platforms*. IGI Global, 2020, pp. 19–34.

[73] J. McDonald, R. Wolfe, J. Schnepp, J. Hochgesang, D. G. Jamrozik, M. Stumbo, L. Berke, M. Bialek, and F. Thomas, "An automated technique for real-time production of lifelike animations of american sign language," *Universal Access in the Information Society*, vol. 15, pp. 551–566, 2016.

[74] L. Ventura, A. Duarte, and X. Giró-i Nieto, "Can everybody sign now? exploring sign language video generation from 2d poses," *arXiv preprint arXiv:2012.10941*, 2020.

[75] R. Bartoszcze, Z. Bauer, E. Chudziński, M. DuVall, S. Dziki, B. Fischer, W. Furman, A. Hess, M. Jasionowicz, S. Jędrzejewski *et al.*, *Słownik terminologii medialnej*. Kraków: Towarzystwo Autorów i Wydawców Prac Naukowych Universitas, 2006.

[76] J. J. Bird, A. Ekárt, and D. R. Faria, "Chatbot interaction with artificial intelligence: human data augmentation with t5 and language transformer ensemble for text classification," *Journal of Ambient Intelligence and Humanized Computing*, vol. 14, no. 4, pp. 3129–3144, 2023.

[77] S. Fontana and G. Caligiore, "Italian sign language (lis) and natural language processing: an overview." *NL4AI@ AI* IA*, 2021.

[78] D. Bragg, O. Koller, M. Bellard, L. Berke, P. Boudreault, A. Braffort, N. Caselli, M. Huenerfauth, H. Kacorri, T. Verhoef *et al.*, "Sign language recognition, generation, and translation: An interdisciplinary perspective," in *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 2019, pp. 16–31.

[79] I. Papastratis, C. Chatzikonstantinou, D. Konstantinidis, K. Dimitropoulos, and P. Daras, "Artificial intelligence technologies for sign language," *Sensors*, vol. 21, no. 17, p. 5843, 2021.

[80] R. Rastgoo, K. Kiani, S. Escalera, and M. Sabokrou, "Sign language production: A review," in *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, 2021, pp. 3451–3461.