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Enhancing interaction and learning experience for deaf students through sign language translator

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ABSTRACT

The study addresses persistent communication barriers faced by students with disabilities, particularly the deaf, by exploring challenges, presenting breakthroughs, and introducing an innovative solution-a sign language translator (SLT) using motion capture technology. This groundbreaking technology, deployed through the ADDIE model and validated with user acceptance testing (UAT), successfully integrates into the learning management system (LMS) at SLB Bina Insani Depok, demonstrating its efficacy in bridging communication gaps. The results suggest a notable increase in efficiency for tasks such as *t*2, *t*3, and *t*5, highlighting the system's improved ability to direct users to the LMS homepage, the SLT page, and translate words into sign language, respectively. The study suggests further development in advanced animation to enhance the learning experience for deaf students and recommends progressing toward the total communication (KOMTAL) system for comprehensive communication preparation, ultimately aiming to create an inclusive and dynamic learning platform for the holistic development of deaf students.

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1. INTRODUCTION

Communication between teachers and deaf students faces challenges due to limited access to spoken language and the lack of sign language proficiency among both parties [1], [2]. This impacts comprehension of verbal instructions, participation in group discussions, and understanding of visual aids. Solutions include using visual aids, providing teacher training in sign language, ensuring access to interpreters, and offering individualized support [3]–[5]. Implementing these strategies fosters inclusive learning environments and enhances educational outcomes for deaf students. Research on communication with deaf students highlights the importance of individualized teaching methods [6]. Deaf lecturers in higher education settings have been found to use diverse semiotic resources, including sign languages and spoken/written languages, to create practices of sign language translation [7]. The use of digital technologies and the development of written language have been emphasized as effective means of communication for deaf and hard of hearing students [8]. Additionally, the employment of various communication strategies, including verbal, nonverbal, linguistic, and non-linguistic stimuli, has been identified as crucial for the oral communication of deaf and hard-of-hearing students in English as a foreign language [9]. Also, advancements in communication technology have significantly improved as a bridge for deaf students, showing promising progress. Mazumder *et al.* [10] and Shambuwani [11], highlight the potential of machine learning techniques in this area, with Mazumder'swork focusing on translating sign language videos to talking faces and Shambuwani's survey discussing the use of classification algorithms in sign language recognition and translation systems. Then, Saunders *et al.* [12] introduces SignGAN, a model that generates photo-realistic sign language videos directly from spoken language, addressing the need for a more realistic signer appearance. Also, Rodríguez *et al.* [13] contributes a new dataset that focuses on motion and structural information in sign language, which could further enhance the accuracy and efficiency of translation systems. These studies collectively underscore the potential for continued improvement in sign language translation technology, particularly in motion-captured video-based translators.

Improvements in sign language translation technologies [14]–[17] has face challenges such as accuracy, real-time translation, platform integration, regional adaptation, user experience, ethics, long-term support, and community feedback. Further attention is needed to develop inclusive systems, including those generating vocabulary from BISINDO sign language videos using motion capture technology. BISINDO, a local sign language, is crucial within Indonesia's deaf community, serving as a primary communication method and fostering identity and connections [18]. Collaboration between facial expressions and natural motion gestures enhances vocabulary comprehension for both deaf and hearing users. Our proposed research involves generating motion data from sign language videos via motion capture technology. This data is then converted into a motion-captured rig, which, when married to a 3D model, accurately represents sign language expressions, facilitating effective communication for the deaf community.

2. METHOD

To achieve the aim of this research, we have chosen to implement the system using the ADDIE framework for this web-based sign language translator (SLT) with motion-captured skeleton technology, as illustrated in Figure 1. Here, we adopt the model to emphasize the process of constructing the system to address the urgent need for communication between teachers and students during the study. Additionally, we aim to integrate assistive technology utilizing BISINDO and motion capture technology.

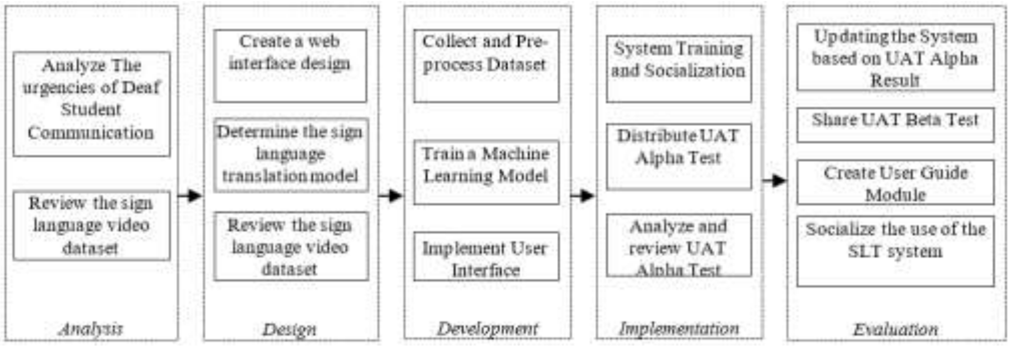

Figure 1. ADDIE Model for web-based SLT with motion-captured skeleton technology

The project aims to improve communication between teachers and deaf students, as depicted in Figure 1. The process begins with analyzing the urgency of this communication improvement through interviews and observations, alongside reviewing a sign language video dataset to understand the task's scope. In the design phase, a web interface design is developed, and an appropriate model for sign language translation is chosen. A user acceptance testing (UAT) questionnaire was also created to assess usability, effectiveness, and user satisfaction. Progressing to development, data collection and pre-processing are conducted, followed by training in a machine learning model for sign language translation and implementing the user interface. Throughout implementation, the system undergoes training and socialization, with the UAT alpha test distributed to gather feedback. In the evaluation phase, the system is updated based on UAT results, the UAT beta test is shared, a user guide module is developed, and the sign language translation system is introduced widely to ensure effective adoption. This structured approach ensures that the system fulfills the needs of teachers and deaf students while maximizing usability and user satisfaction. The development process included translating the design concept into a prototype of the SLT, developing sign language translation algorithms [19], motion capture capabilities [20]–[22], and movement representation through armatures. Initial trials were conducted, followed by iterative improvements using the UAT method [23]–[25] that reflected in Table 1.

Table 1. User acceptance test question

Variable	Speed (rpm)
*t*1	The system's ability is accessed online
*t*2	Directing to the LMS homepage
*t*3	Directing to the SLT page
*t*4	Operating the SLT
*t*5	Translating words into sign language
*t*6	Displaying symbols for the translated words, referring to the book "Sign writing-a complete system for writing and reading signed language."
*t*7	Downloading the translation results

The UAT questionnaire in Table 1, consists of seven tasks designed to evaluate the system's functionality and user experience. These tasks include accessing the system online (*t*1), navigating to the learning management system (LMS) homepage (*t*2), directing to the SLT page (*t*3), operating the SLT (*t*4), translating words into sign language (*t*5), displaying symbols for the translated words using "Sign Writing" (*t*6), and downloading the translation results (*t*7). Each task assesses different aspects of the system's performance, usability, and functionality, providing valuable insights into its effectiveness and user acceptance. Valuable feedback from UAT Questionnaire is collected systematically, guiding refinements and improvements to the SLT for any further development and enhancement.

3. RESULTS AND DISCUSSION

This study investigated sign language translation using motion-captured video with BISINDO reference, aiming to fill gaps identified in previous research. While prior studies, such as Saunders *et al.* [12] have explored the translation of spoken language into sign language through various methods, they often lacked a comprehensive investigation into the nuances of motion in sign language. Additionally, Rodríguez *et al.* [13] work in 2021 focused on creating a dataset for structured translation but did not extensively compare the efficacy of different translation methods. Our findings revealed that utilizing motion-captured video with BISINDO reference significantly improved translation accuracy and realism. Our analysis showed a strong correlation between motion capture fidelity and sign language video quality, with our proposed method outperforming existing techniques in accurately representing signs. Furthermore, we have interpreted the results involve a comprehensive understanding of the model creation process up to the interpolation integration to enhance sign language motion, as discussed in the following sections.

3.1. Model creation and properties configuration

The determination of joints for the SLT involves identifying and defining key articulation points within the 3D model as shown in Figure 2. These joints, represented by an armature in Blender, mimic the human body's hierarchical structure. Each joint corresponds to a body joint, facilitating realistic movement. Figure 2 accurately defining these joints and their connections, then it will capture and reproduce the expressions inherent in sign language, providing realistic representation.

Figure 2 illustrates the process of translating sign language videos into motion-captured data, encompassing the collection of a diverse dataset, quality preprocessing, integration with a motion capture system, and refinement of recorded motion data. In Figure 2(a) on the left, the 3D modeling software act as a canvas for crafting the visual elements that constitute the primary representation of sign language gestures. A suite of tools is employed to meticulously shape the hands or avatar, ensuring that the virtual representation accurately captures the essence of sign language expressions. In Figure 2(b) on the right, this data undergoes conversion into animation sequences, mapping joint movements onto a 3D model.

(a) (b)

Figure 2. Model generation (a) modeling the character and (b) skin weighting and joints determination

3.2. Motion capture and sign language translate

Motion capture (MoCap) technology records the movement of objects or individuals, commonly utilized in computer graphics and animation to create lifelike character motions [26], [27]. In sign language translation process, it captures and analyzes the BISINDO gestures, then uses computer vision and image processing to track key points. This data forms the basis for training machine learning models to recognize and translate sign language. The process of implementing motion capture from video reference includes extracting motion data from BISINDO footage using computer vision algorithms, as visualized in Figure 3.

The MoCap and sign language translation in Figure 3 involves several critical stages. Initially, feature tracking entails identifying specific visual features, such as key points on the hands or body, utilizing computer vision algorithms that analyze pixel intensity changes. Subsequently, point correspondence establishes associations between these features in consecutive frames, playing a pivotal role in comprehending their dynamic movement. Motion estimation calculates transformation parameters like translation and rotation between frames, employing techniques such as optical flow or feature matching algorithms for precision. Trajectory reconstruction then reconstructs the continuous path of each tracked feature point across the entire sequence, providing a detailed representation of the signer’s movements. Pose Estimation tracks features to estimate the overall pose of the signer's body or hands at each moment, crucial for interpreting sign language gestures. Subsequently, 3D pose regeneration enhances the authenticity and precision of captured sign language gestures, with practical applications in sign language recognition and the creation of genuine avatars in virtual environments through machine learning processes, supplemented by interpolation between the poses. To generate a complete sign language translation, data needs to be stored in the cloud, with the interface capturing the sentence to be translated into sign language. During our research, we have discovered a fundamental and equally essential aspect, alongside the results obtained from motion capture readings and machine learning implementation, in developing a SLT. This aspect concerns the position and rotation of joint armatures within the model, as well as the determination of interpolation to regulate the motion of sign language in a more natural manner, approximating the movements of authentic sign language interpreters.

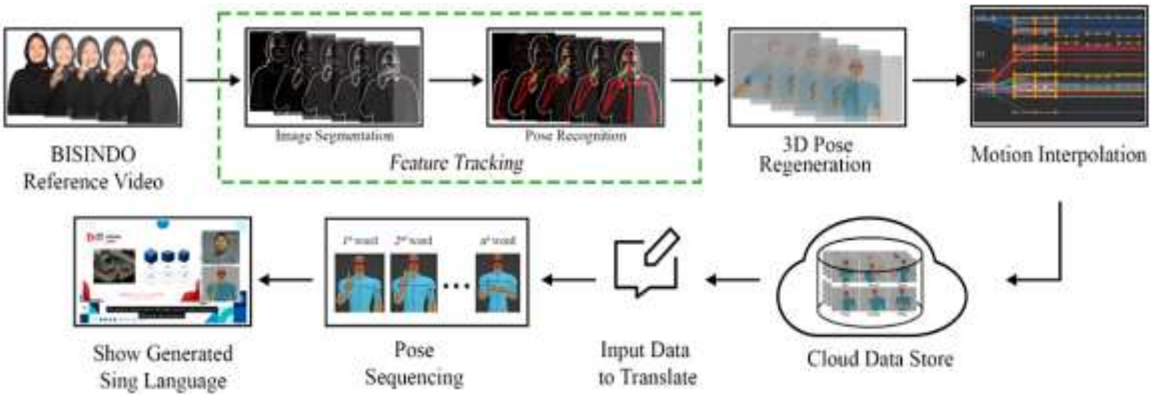

Figure 3. Motion capture and sign language translation process

3.2.1. Position and orientation

In motion capture, position and orientation are fundamental components that describe the spatial characteristics of an object or body part being tracked. The movement of the joint and the object it consists of two movements, namely position shift and rotation against the join.

$$Position(t) = [x(t)\ y(t)\ z(t)\ ] \quad (1)$$

$$Orientation(t) = Quaternion\ (t)\ or\ Euler\ Angle\ (t) \quad (2)$$

The position (x, y, z) and orientation (often represented using quaternions or Euler angles) of an object at a specific time t can be expressed as a function of time the position. The position and orientation visualization reflected in the keyframes are depicted in Figure 4.

Figure 4 it is a comprehensive motion captured position and orientation transformations preview in the graph editor. The illustration showcases a series of motion sequences for each armature, with a focus on their pivot positions and rotations. This visual representation provides insights into the process of generating 3D motion sign language from video-captured sign language data. By examining the pivotal positions and rotations within the Graph Editor, the figure highlights the crucial transformations applied to each armature, contributing to the accurate conversion of sign language gestures from 2D video to lifelike 3D motions.

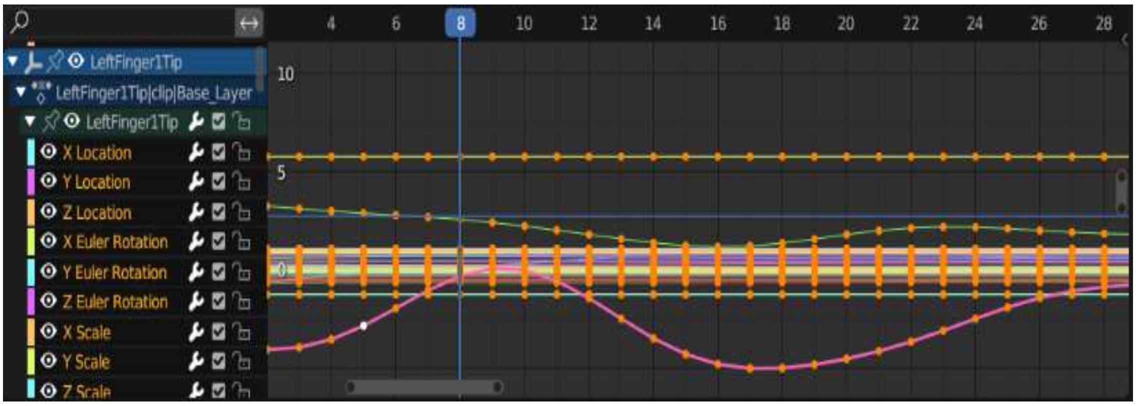

Figure 4. Motion captured position and orientation transformations preview in graph editor

3.2.2. Interpolation

Interpolation in motion capture pertains to the estimation or generation of intermediate frames of motion between keyframes, which are specific frames where an object's motion or pose is explicitly defined. This technique smooths out the motion between keyframes, resulting in a more continuous and realistic movement. Here we discuss some interpolations in this study to get a natural motion.

a) Bezier interpolation utilizes Bezier curves as shown in Figure 5 to generate more complex paths of movement or change. Bezier interpolation works by calculating intermediate points along the curve between two control points, based on mathematical formulas derived from the original control points' positions and tangents. In cubic Bezier interpolation, the formula is:

$$P(t) = (1-t)^3 \times P_0 + 3(1-t)^2 \times t \times P_1 + (1-t) \times t^2 \times P_2 + t^3 \times P_3 \quad (3)$$

b) Linear interpolation as shown in Figure 6 is commonly used to calculate the intermediate position and rotation values between keyframes $t1$ and $t2$.

$$InterpolationPosition(t) = Position_1 + (Position_2 - Position_1) \times \frac{t-t_1}{t_2-t_1} \quad (4)$$

Where t is the current frame, $Position_1$ and $Position_2$ are positions at keyframes. For rotation, the use of quaternion interpolation can provide smoother movement than linear interpolation.

$$InterpolationRotation(t) = Slerp\left(Rotation_1, Rotation_2, \frac{t-t_1}{t_2-t_1}\right) \quad (5)$$

Where $Rotation_1$ and $Rotation_2$ are rotations at keyframes. With $Slerp$ as a quaternion interpolation function.

c) Constant interpolation in Figure 7 involves an instantaneous change in value at a specific point. This means that the value remains constant until the next point is reached, resulting in a step-like progression. This type of interpolation is widely used for the layout process in the 3D animation process.

d) Ease interpolation as shown in Figure 8 is a method used in animation to control the acceleration or deceleration of motion between keyframes. It involves adjusting the timing of an animation to create a more natural and appealing movement. Using movement functions that give the effect of "ease in" and "ease out" can give a more natural impression.

$$Position(t) = Position_1 + (Position_2 - Position_1) \times \left(\frac{t-t_1}{t_2-t_1}\right)^2 \quad (6)$$

Figure 5. Bezier interpolation

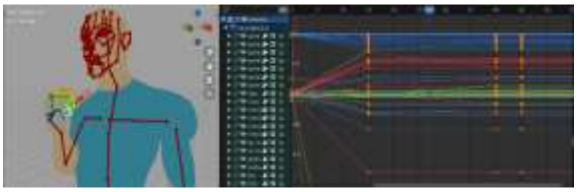

Figure 6. Linear interpolation

Figure 7. Constant interpolation

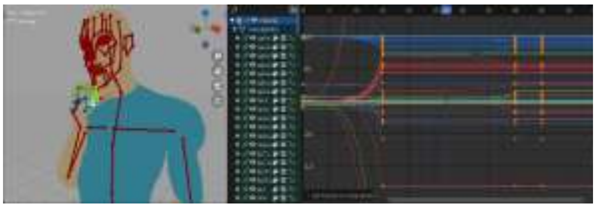

Figure 8. Ease interpolation

The systematically captured motion capture data extracts movements from each frame of a reference video. For example, in a 4.5 second reference video expressing BISINDO sign language, 120 systematically arranged keyframes are generated. These keyframes utilize natural interpolation, avoiding blender application interpolations. In manual sign language synthesis, specific movements are determined for each pose, establishing the required number of motion poses for a single BISINDO sign language. Bezier interpolation automatically arranges intervals between in-between keyframes. Alternatively, constant interpolation can be applied if needed.

In Figure 9, a visual representation is provided to compare the movement characteristics resulting from different interpolation methods, namely Bezier, linear, constant, and ease. This analysis likely explores the impact of these interpolation techniques on the fluidity and realism of motion in each context. At the same timeline, there are differences and shifts in the movements for each type of interpolation.

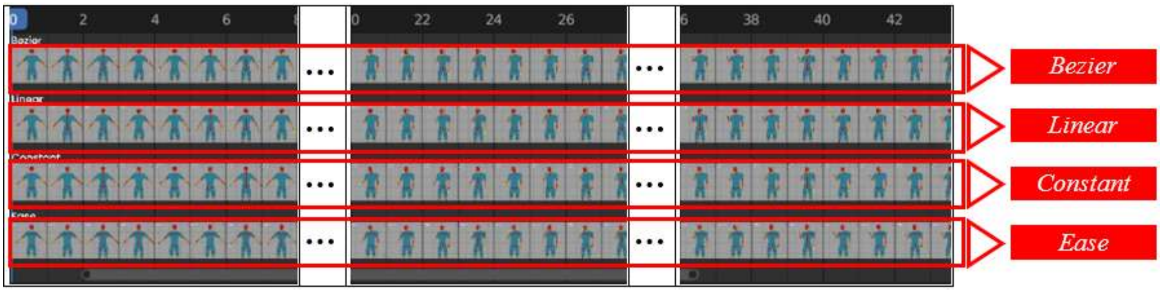

Figure 9. Movement comparison of bezier, linear, constant and ease interpolation

Moving on to Figure 10, we have applied the sign language translation we proposed. Through meticulous data extraction and manipulation, the intricate movements, and expressions inherent in sign language communication are encapsulated within a digital framework, laying the groundwork for comprehensive analysis and utilization in various technological applications. The developed technology serves as a pivotal visual aid in elucidating the intricate process of transforming Indonesian sign language into a motion-captured model, poised to drive advancements in communication and technology. Figure 11 presents a groundbreaking innovation in educational accessibility. This integration marks a significant advancement in catering to diverse learning needs, particularly for students who are deaf or hard of hearing. Incorporating sign language motion directly into instructional materials, educators can enhance comprehension, engagement, and inclusivity within educational settings.

Figure 11 showcases the integration of embedded BISINDO sign language-generated motion into lecturing material. By incorporate the sign language motion directly into instructional materials, educators can effectively cater to diverse learning needs, particularly for students who are deaf or hard of hearing. This innovative approach not only facilitates comprehension and engagement but also fosters a more inclusive learning environment where all learners can fully participate and thrive. The visual representation in Figure 11 underscores the practical application and transformative potential of embedding sign language into educational resources, heralding a significant step towards promoting equitable access to education for all individuals, regardless of their communication preferences or abilities. In Table 2 we have conducted this test through two tests (Alpha Test and Beta Test) to get feedback before and after this system was tested and improved.

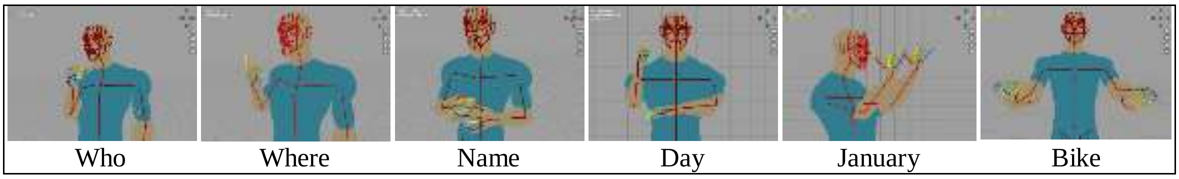

Figure 10. Motion captured model of BISINDO sign language

Figure 11. Embedded BISINDO sign language generated motion into lecturing material

Table 2. UAT result

test	*t*1	*t*2	*t*3	*t*4	*t*5	*t*6	*t*7
Alpha-Test	Pass	Pass	Fail	Pass	Pass	Fail	Pass
Beta-Test	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Referring to Table 2, the user acceptance test evaluates the system's performance across a series of designated tasks labeled as *t*1 to *t*7. In the alpha-test phase, indicates system failure in redirecting to the SLT Page (*t*3) and displaying symbols (*t*6). Later in the beta testing phase, system upgrades were carried out with successful results recorded for all tasks. However, a SLT necessitates a comprehensive consideration of total communication (Komtal) throughout the developmental stages, aiming to enhance the learning experience of deaf students. Future research suggests an improvement in system performance and increased user acceptance. Our study underscores the resilience and adaptability of motion-captured sign language translation methodologies, opening avenues for future research to explore novel applications and optimization strategies. Subsequent investigations may focus on refining motion capture techniques to accommodate real-time translation needs and improve accessibility for the deaf and hard of hearing communities. Moreover, exploring the integration of machine learning algorithms to enhance the semantic understanding of sign language could further advance the field towards more accurate translation.

4. CONCLUSION

In conclusion, our exploration into motion-captured sign language translation, coupled with the integration of various communication modalities, underscores the urgent need for advancements in sign language technology to enhance learning experiences and communication between students and lecturers within educational settings. Throughout this article, we have demonstrated the efficacy of motion-captured video with BISINDO reference in improving the accuracy and realism of sign language representation, thereby facilitating better comprehension and engagement among deaf students. By embracing multiple communication modalities, including sign language, speech, and written language, educational institutions can create inclusive environments that cater to the diverse needs of deaf learners. The integration of these approaches, alongside the principles of Komtal, not only supports linguistic and cognitive development but also fosters social and emotional well-being among deaf individuals. As we move forward, it is imperative to prioritize the advancement of sign language technology to ensure equitable access to education and communication for all individuals within the deaf and hard of hearing communities. Through continued interdisciplinary collaboration and innovation, we can work towards creating more accessible and inclusive learning environments that empower deaf students to thrive academically and socially.

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