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An Adaptive, Affordable, Open-Source Robotic Hand for Deaf and Deaf-Blind Communication Using Tactile American Sign Language

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Abstract— **Currently, $\sim$1.5 million American deaf-blind individuals depend on the availability of interpreting services to communicate in their primary conversational language, tactile American Sign Language (ASL). In an effort to give the deaf-blind community access to a device that facilitates independent communication using tactile ASL, we developed TATUM (Tactile ASL Translational User Mechanism). TATUM employs 15 degrees of actuation in a hand-wrist system that is capable of signing the 26-letter ASL alphabet. Leveraging Interpres, an independent cloud-based service, all servo sequences that render desired fingerspelled letters and ASL words are stored in a web application programming interface (API). A validation study including both deaf and deaf-blind participants confirmed that the TATUM hand mimics a human hand both in size and feel. The current design of TATUM attained an average recognition rate of 94.7% in visual validation, indicative of the potential to support deaf and deaf-blind individuals in communicating via visual and tactile ASL.**

I. INTRODUCTION

With recent innovative technological advances, disabled individuals are now gaining access to assistive devices to aid the day to day activities in their personal environment [1]. A major focus in designing assistive devices is increasing access to communication for individuals with cognitive and physical disabilities. Despite this push, the deaf-blind community still lacks access to means of communicating in their primary conversational language, tactile sign language (ASL). Sign language includes a fingerspelled alphabet for proper nouns, while grammar and vocabulary are expressed using a combination of facial gestures and hand gestures with bodily positional references.

Deaf-blindness is characterized on a spectrum that ranges from partial visual and/or hearing impairment to complete loss of the two senses. The National Health and Nutritional Examinations survey that ran from 2006 to 2013 discovered that $\sim$1.5 million Americans have some degree of vision and hearing loss [2]. While deaf-blindness is highly prevalent amongst the elderly population [3], it is also found in younger individuals with hereditary conditions like Usher syndrome [4]. Usher syndrome, which accounts for 50% of hereditary deaf-blindness cases [5], has an estimated prevalence of 1 in 6000, amounting to over 50,000 children in the United States alone [6]. To communicate, deaf-blind individuals in the United States use a combination of Braille, American Sign Language (ASL), and tactile alphabets.

Fig. 1. The adaptive, affordable, open-source TATUM robot hand-wrist system signing the letters A (left), S (center), and L (right).

Advancements in communication devices for the deaf-blind community have focused on Braille displays. Equipped with a refreshable 80 character screen, Braille displays allow users to access information from computers or other mainstream devices independently [7]. However, Braille displays are extremely expensive (limiting accessibility) and difficult to utilize for extended periods of time (more than 30 consecutive minutes), especially for those with multiple disabilities [8]. Most importantly, Braille is a less efficient communication tool for deaf-blind individuals, as reading Braille is 30% slower than ASL [9], [10] and requires the use of a secondary communication language.

On the other hand, current communication methods that employ tactile ASL require the use of an interpreter, thus limiting the independence of deaf-blind individuals. To utilize tactile ASL, the deaf-blind person places their hands on their signing partner's hands, tracking movements and handshapes as their partner signs. As a result, deaf-blind individuals cannot rely on their preferred conversational language to interact with non-tactile ASL signers without the use of an interpreter. This limitation severely hinders deaf-blind individuals ability to communicate with those in and outside of their community, relying on the availability of an interpreter for all means of contacting those around them. This issue has intensified during the COVID-19 pandemic, when physical distancing regulations have prevented close contact between people (e.g., deaf-blind individuals and their interpreter or signing partner). Therefore, a compelling need exists for designing, developing, and disseminating an open-source, low-cost robot hand that supports the signing of tactile ASL

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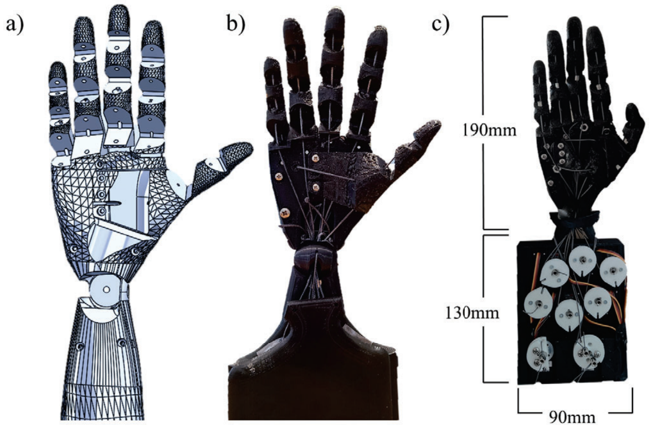


Fig. 2. SolidWorks CAD model of the designed robot hand-wrist system (a) and physical model of the 3D printed prototype (b), with a total system height of 320 mm and width of 90 mm (c).

through integration with mainstream communication devices without requiring assistance from an interpreter. Several designs of robotic hands for ASL applications have been proposed over the last decades. In 1977, the SouthWest Research Institute (SWRI) developed a mechanical hand that used a text input from a connected keyboard to fingerspell desired messages. However, deaf-blind individuals found it difficult to use it as an effective communication tool since it was unable to sign most letters, signed slowly, and lacked smooth movements [11]. Project Dexter later proposed a robotic hand with an anthropomorphic appearance and improved ASL signing capability, achieving a recognition rate of 70% in ASL alphabet handshape validation studies with deaf-blind participants. This hand was driven by pneumatic cylinders pulling on cables connected to individual fingers, limiting accessibility of the device [12]. Additionally, similar to the SWRI hand, Dexter lacked a wrist and therefore could not sign letters such as J, P, Q, and Z. RALPH was the first robotic hand designed specifically for facilitating communication of deaf-blind individuals [13], in that it provided sufficient torque to overcome the pressure imposed by the user's hand. This device featured a linkage mechanism driven by servos and a personalized user interface to allow for modifications in finger positions. However, RALPH required eight hours of instruction with varied validation results for fingerspelling [11]–[13].

In an effort to sign more anthropomorphically, the PARLOMA project integrated a 3D printed robotic hand with a remote communication system, which employed a low cost camera to provide gesture recognition of handshapes and gestures that could be used to control the hand motion [14] [15]. The hand supported abduction and adduction of the index finger, middle finger, and thumb, enabling it to reproduce most ASL letters. Furthermore, the design included a wrist mechanism equipped with a 3 Degrees of Freedom (DoF) parallel manipulator, which allowed the device to sign down letters (e.g., P and Q). Leveraging a combination of linkage and tendon driven mechanisms, PARLOMA achieved a 90% success rate in visual recognition of ASL alphabet handshapes, though excluding E, G, J, M, N, Q, R, T, U, Z [14], [15]. Moreover, feedback from only one deaf-blind user was collected, and the results of the tactile recognition rates were not reported. While PARLOMA improved many drawbacks of existing fingerspelling hands, it still lacked an anthropomorphic feel, being composed of mostly rigid components and mechanisms, such as linkages.

Traditional design methodologies [16] that utilize dexterous manipulators made of rigid components could potentially harm the user's hand during signing, e.g., the user's fingers may get pinched between the gaps of a linkage mechanism when the robotic hand performs flexion or extension motions. This risk is particularly high in the case of deaf or deaf-blind users that cannot have real-time feedback of the complete configuration of the robot hand and rely on the perceived forces to estimate the handshapes.

In this work, to overcome the drawbacks of existing devices, we present the TATUM platform (Tactile ASL Translational User Mechanism), an adaptive, open-source, affordable robotic hand-wrist system that is capable of signing the 26-letter ASL alphabet and other complex signs (Fig. 1). The use of 3D printed thermoplastic polyurethane (TPU) and polylactic acid (PLA) components, combined with a tendon actuation scheme, renders the proposed device low-cost and easy to assemble, maintain, and repair, improving accessibility. When signing, users place their hands above the wrists of the interpreter's hand in order to communicate. Hence, the robotic hand has been designed to be anthropomorphic and to provide users with a familiar interaction experience when communicating via the device (see Fig. 2). TATUM utilizes a WiFi module to connect to the user's email and other internet based communication services via Interpres, an independent cloud-based service that facilitates communication. Based on preliminary analysis and feedback from the deaf-blind community, we expect TATUM to revolutionize deaf-blind involvement with their community and create a pathway for communication with non-tactile ASL signers.

II. DESIGN AND METHODS

In this section, we present the design of TATUM (Fig. 2) and the methods used to facilitate communication of deaf and deaf-blind people using tactile ASL.

A. *Robotic Hand-Wrist System Design*

The robotic hand-wrist system design is based on an open-source anthropomorphic hand model [17], in which additional mechanical joints and attachment points were added to execute complex motions in an anthropomorphic manner. To enable safe interactions during signing procedures and prevent the device from harming the user, we employed a tendon driven transmission mechanism and flexure joints [18], which produce a soft and compliant behaviour within the fingers of the hand. It should also be noted that the proposed robotic hand is designed so as to leave no gaps during actuation and prevent the user's hand and fingers from

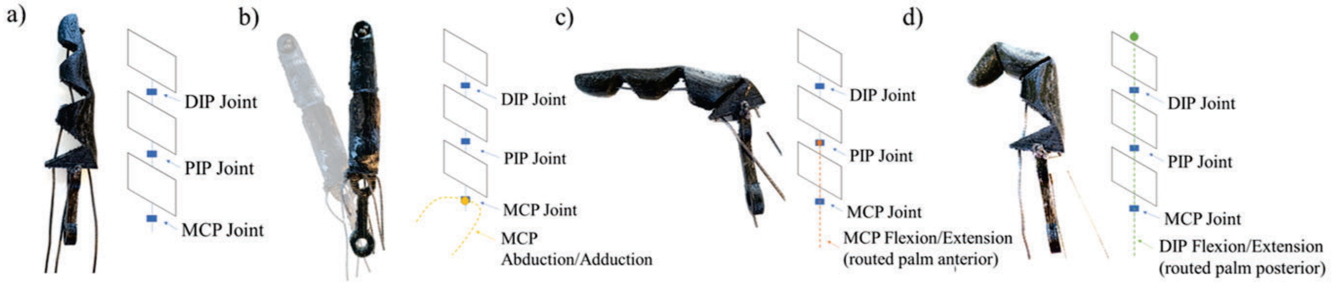


Fig. 3. The 3D printed TATUM finger design is depicted in: a) the rest state, b) abduction configuration at the MCP joint, c) flexing at the MCP joint, d) flexing at the DIP and PIP joints simultaneously.

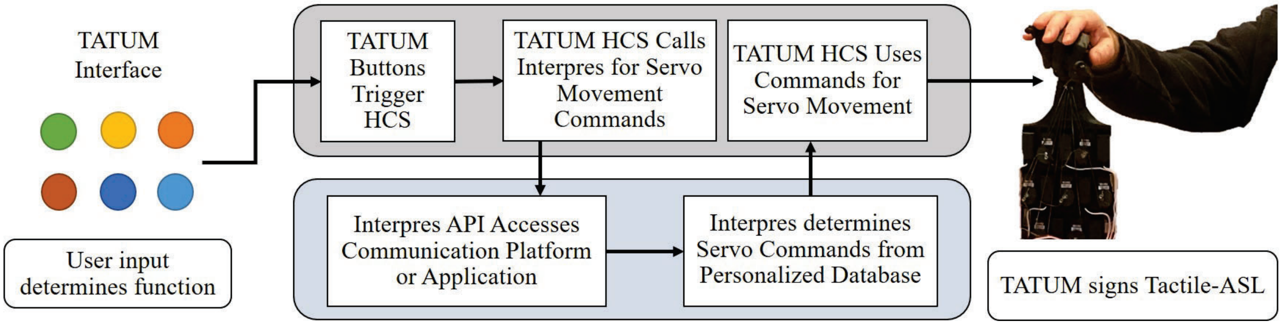


Fig. 4. A schematic diagram of the system. The user will select an application button, like 'Learn,' causing the hardware control system (HCS) to call to the independent cloud-based service Interpres for the commands used for servo movement.

being caught within the mechanism's structure. Furthermore, since deaf-blind users physically interact with the TATUM hand alone, the proximal components of the system that require higher load bearing capabilities were designed with rigid materials. Amongst those is the wrist, which supports the weight of the user's hand while resting on the robotic hand during signing.

The TATUM hand-wrist system is composed of 15 servos (10 Goteck GS-9025MG 9g servos connected to the fingers and 5 FEETECH FS5103B servos employed to control the wrist and thumb motions), and a microcontroller (Arduino Mega). The fingers are made out of TPU, while the remaining parts of the hand are created using PLA. To achieve the various letters of the ASL alphabet, the 15 degrees of actuation (DoAs) of the hand are distributed amongst the five fingers. The ring and pinky fingers are composed of 2 DoA each, the first attached to the flexion of the metacarpophalangeal (MCP) joint and the second coupled to the flexion of the proximal interphalangeal joint (PIP) and the distal interphalangeal joint (DIP), as depicted in Fig. 3c and Fig. 3d, respectively.

Unlike the ring and pinky fingers, the index and middle fingers require an additional DoA to sign letters that involve abduction of the fingers, like R or V, as illustrated in Fig. 3b. The thumb consists of 3 DoAs allocated to the opposition of the thumb, the thumb carpometacarpal (CMC) joint, and the simultaneous flexion of the MCP/DIP joints of the thumb. The final 2 DoAs of the proposed robotic hand are allocated to wrist flexion and abduction.

B. Hardware Control Software

TATUM's hardware control software (HCS) is written in C++ and utilizes Arduino libraries to interact with the selected hardware components. Notwithstanding the complexity of the hardware, the TATUM's HCS primarily focuses on basic functionality, such as button activity (e.g., power on, stop, next, etc.), and servo control and movement. TATUM's HCS utilizes a Wi-Fi module (ESP32) to connect the TATUM platform to the internet and gain access to Interpres, where the commands for signing different ASL letters are stored and processed. By ensuring the HCS only executes commands that Interpres provides, the overall system can be continually updated without updating the HCS. A diagram describing how the hand is controlled is shown in Fig. 4.

C. Interpres

Interpres is an independent cloud-based service that TATUM accesses through the Interpres application programming interface (API). Interpres translates text into servo-based instructions and relays those back to TATUM. TATUM's HCS then applies the servo control instructions to create the required handshapes. The API allows for the continuous update of the database of known complex signs and grammar without requiring any action from the user, ensuring that the TATUM hand can be customized to be effective for different users. Interpres has the ability to access and consume account messages from communication applications installed on electronic devices (e.g., documents, emails, and texts in computers and cellphones).

TABLE I

SURVEY QUESTIONS ASKED TO DEAF-BLIND PARTICIPANTS AFTER THE TACTILE RECOGNITION EXPERIMENTS AND NUMBER OF VOTES ALLOCATED TO EACH POSSIBLE ANSWER.

Questions	**Score**				
Size of Hand	**Very Small (-2)**	**Small (-1)**	**Just Right (0)**	**Big (1)**	**Very Big (2)**
	0	0	2	1	0
Feel of Hand	**Very Stiff (-2)**	**Stiff (-1)**	**Just Right (0)**	**Flexible (1)**	**Very Flexible (2)**
	0	0	3	0	0
Speed of Transition	**Very Fast (-2)**	**Fast (-1)**	**Just Right (0)**	**Slow (1)**	**Very Slow (2)**
	0	0	3	0	0
Speed of Movement Letters	**Very Fast (-2)**	**Fast (-1)**	**Just Right (0)**	**Slow (1)**	**Very Slow (2)**
	0	1	2	0	0

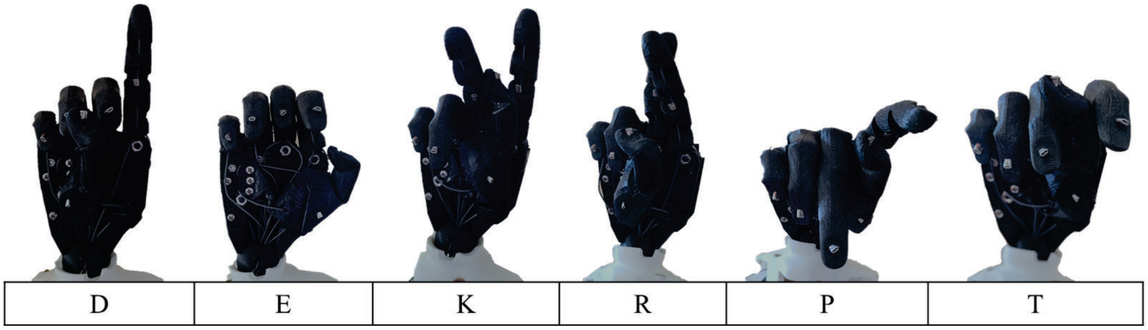


Fig. 5. The signing capabilities of the TATUM hand and wrist are demonstrated through the execution of all the gestures needed to sign complex ASL letters such as the D, E, K, R, P, and T.

D. Validation

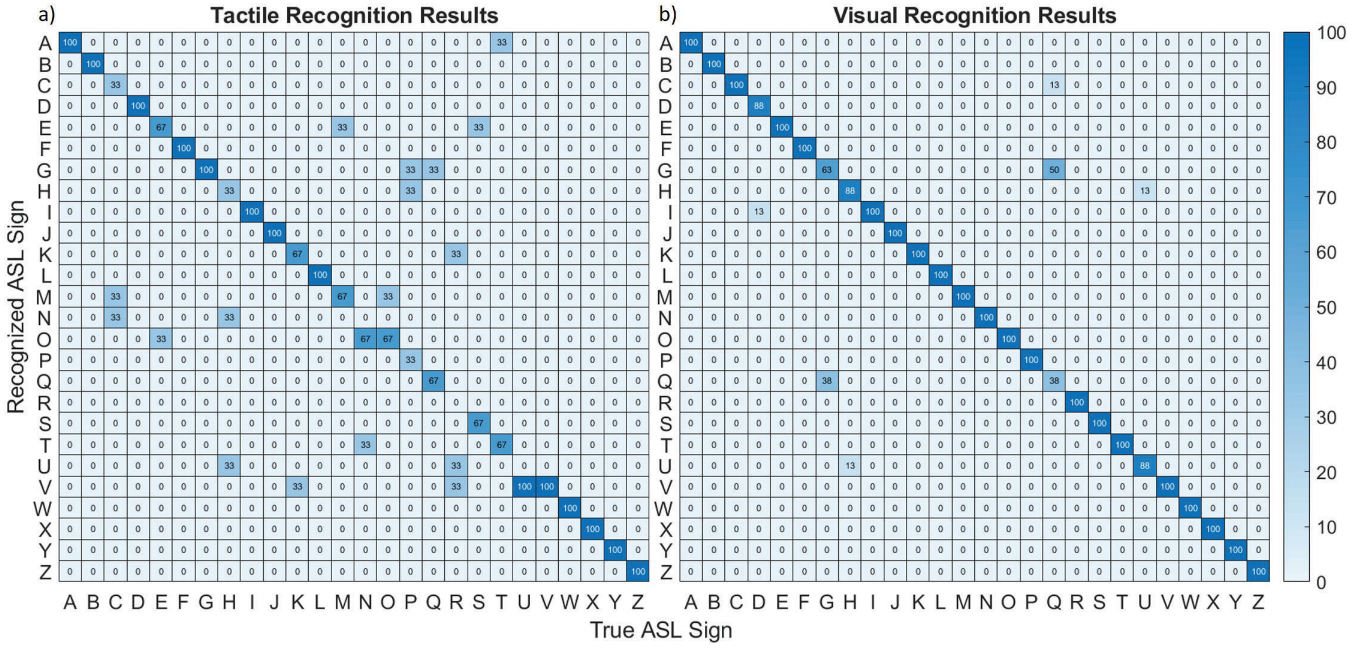
To validate the efficiency of the proposed robotic hand-wrist system, we conducted a series of trials with deaf (n = 8) and deaf-blind (n = 3) participants who have tactile-ASL as their primary language. The goal of the trials was to determine the user's recognition rate of the 26-letter ASL alphabet when using the device, as well as to gather feedback on the shape, feel, speed, and overall user experience. The validation protocol (approved by Northeastern University Institutional Review Board on 01/13/21; IRB #: 21-01-16) included two different sessions. In the first session (45 minutes), participants were introduced to the letters as signed by the device via the TATUM 'Learn' feature. Within this module, the user prompts the system to sign the ASL alphabet by means of application buttons that are located directly on the hardware, including navigation buttons (next, previous, tag, and restart) to move between letters. In a later session, participants were asked to recognize the handshapes as letters when presented in a random order.

After the tactile handshape recognition trials, participants provided feedback regarding the size of the hand, the feel/stiffness of the hand, the speed of transitions, and the speed of motion for letters that require a sequence of positions instead of a singular handshape (e.g., J and Z). Each of the questions could be scored from -2 to 2, with -2 being very small, very stiff, or very fast and 2 being very large, very flexible, or very slow, depending on the specific question. Additionally, we collected qualitative feedback regarding the four questions on the survey and the letters that needed signing execution improvement.

III. RESULTS AND DISCUSSION

Fig. 5 illustrates a subset of the handshapes as signed by TATUM. In the validation studies, the design of the robotic hand-wrist system with HCS and Interpres integration was evaluated for efficacy and safety. The confusion matrices illustrated in Fig. 6 report the tactile and visual recognition rates for each letter, as well as the letters/handshapes for which they were confused. The averaged recognition rate of the 26 handshapes was 94.7% for the visual experiments and 71.7% for the tactile experiments. The latter validation with the deaf-blind participants, however, was only performed with an earlier TATUM prototype, which lacked the additional DoA that was introduced in the thumb to actuate the CMC joint. Feedback from that session was used to improve the design and achieve the reported, improved recognition rate for the visual validation. Tactile validation of the newer version of TATUM has yet to be performed due to COVID-19 restrictions.

Updates to the design following the early validation with the deaf-blind participants allowed for better rendering and visual recognition of bent-palm handshapes (i.e., O, C, M, N, T), for which accurate placement of the thumb is necessary. As an example, the thumb needs to contact the interdigitated fold between the middle and index finger in



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0
B	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	67	0	0	0	0	0	0	0	33	0	0	0	0	0	33	0	0	0	0	0	0	0
F	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	33	33	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	33	0	0	0	0	0	0	0	0	0	67	0	33	0	0	0	0	0	0	0	0	0	0	0
N	0	0	33	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	33	0	0	0	0	0	0	0	0	67	67	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	67	0	0	0	0	0	0
U	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	33	0	0	100	100	0	0	0	0
W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0
Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
D	0	0	0	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	63	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	88	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0
I	0	0	0	13	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0
U	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	88	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0
W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0
Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100

Fig. 6. The confusion matrices showcase the recognition rates of the tactile (a) and visual (b) recognition experiments across the 26 letters of the ASL alphabet. The non-diagonal elements of the matrices reveal the misclassification instances, shading light on which letters each hand sign has been wrongly identified with.

order to differentiate T from O. Additionally, improvements to the abduction of the index finger allowed differentiation between the handshapes for U and V, which are very similar. Despite the design revisions, participants still struggled to differentiate G from Q, which necessitates clear flexion of the wrist, since the handshape for the two letters is the same.

The qualitative feedback from the survey confirmed that the current design of the TATUM platform achieved an anthropomorphic feel, as deaf-blind participants compared it to a female's hand. Moreover, no participant perceived the movements of the robotic hand could cause them harm. Nevertheless, participants strongly agreed that elbow motions should be incorporated to improve the clarity of signing.

The survey further requested deaf-blind individuals to provide a semi-quantitative score on several aspects of the design (Table I). All participants indicated that TATUM provided adequate feel/stiffness and transition speed between signs. Only 1 out of the 3 deaf-blind individuals reported that the size of the hand was big, while the other 2 agreed that the size was appropriate. Lastly, 2 of the 3 deaf-blind participants felt that the speed of signing (∼1 sign/second) was acceptable, while 1 participant believed the TATUM signed too fast. This may have occurred because the current design uses only the wrist motion to implement letters like J and Z (i.e., letters that require a sequence of positions instead of a singular handshape). Improved motion capabilities may be attained by inclusion of an elbow joint, which would reduce the signing speed. Note, however, that even with this addition Interpres will continue to permit signing speeds exceeding the fastest rate identified in [10], which is essential since visual ASL is often faster than tactile ASL.

IV. CONCLUSION AND FUTURE WORK

We presented here the TATUM platform, an adaptive, affordable, and open source anthropomorphic robotic hand-wrist system that can facilitate communication of deaf and deaf-blind people using tactile ASL. TATUM is composed of 3D printed components to ease the fabrication and maintenance of the device while improving its accessibility. The proposed adaptive robotic hand also features soft, tendon driven fingers, which facilitate safe interactions with deaf-blind users during the execution of tactile ASL signs. Finally, our system is integrated with Interpres to convert communication inputs from electronic devices (e.g., emails, messages etc.) into servo sequences that produce ASL signs.

In order to validate the efficiency of the TATUM platform, we conducted experiments involving deaf and deaf-blind individuals in visual and tactile recognition trials. Using the validation study to understand the necessary design improvements, TATUM was updated to give the thumb a new actuation scheme, an updated wrist configuration, and a revised abduction pattern. By being able to differentiate similar handshapes (i.e., U, V, R) as well as bent-palm handshapes (i.e., O, C, M, N, T) more accurately, the supplementary visual validation yielded an averaged recognition rate of 94.7%. The visual recognition rate is promising and, thus, we expect improved tactile recognition rates in the next validation with deaf-blind individuals.

Future work will include tactile validation trials of the updated robotic hand-wrist design. We will also increase the range of motion for the wrist abduction, so as to allow for differentiation between letters with similar handshapes. Furthermore, we will add an elbow mechanism to emphasize the motions that are necessary both for proper rendering of specific letters (e.g., J and Z) and to communicate words and phrases requiring precise spatial positioning (e.g., the signs for 'man' and 'woman', which use the same handshape but necessitate placement of the hand on the signer's forehead and chin, respectively). To do so, we will optimize the mechanical compliance of the elbow structure to achieve a safer tactile communication experience. Additionally, we will use the WiFi module, currently integrated into the HCS to connect TATUM to the internet, to access electronic messaging services like Gmail, Outlook, and Twitter. Finally, we will give users the option to tailor the device to their specific needs (e.g., speed, language, messaging platforms, etc.) by giving them access to the Interpres website.

In conclusion, based on the presented preliminary validation results and user feedback, the TATUM platform emerges as an invaluable tool that deaf-blind individuals can rely on to consistently maintain connection with their community, using their primary conversational language, without the need of an interpreter.

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