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An information-theoretic metric for automated lexicographic selection in Bengali Sign Language

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Abstract. Creating solutions to help the hearing impaired individuals who use Bengali Sign Language, which is considered a low-resource language, is a challenge due to a lack of resources and expert availability. This paper introduces a novel information-theoretic metric, the Information Value for Sign Lexicography (IV-SL), designed to automate the lexicographic selection process for sign language dictionary development. The proposed framework uses a Python-based implementation, which incorporates MediaPipe Holistic for the extraction of visual-kinematic features, including handshapes, movement trajectory, and facial expressions, as well as Word2Vec for the semantic relationships between the gloss word embeddings of the Bengali language. An iterative selection mechanism prioritizes signs based on maximum information gain per dictionary entry, balancing rarity and diversity to minimize redundancy while ensuring broad lexical coverage. Experimental validation demonstrates that the IV-SL metric produces prioritized lexicons with strong alignment to expert linguist judgments, significantly outperforming frequency-based baselines. Initial validation was conducted on a synthetic dataset (880 samples) with simulated phonological features. Confirmation on real-world Bengali Sign Language video data remains a subject for future research. The scientific novelty of this research lies in the principled application of informativeness and diversity criteria – concepts drawn from active learning theory – to sign language lexicography, offering a scalable, reproducible solution for under-resourced sign languages.

Keywords: sign language lexicography, low-resource languages, Bengali Sign Language (BdSL), information value, corpus linguistics, MediaPipe.

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Информационно-теоретическая метрика для автоматического лексикографического отбора в бенгальском жестовом языке

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Резюме. Создание решений для помощи людям с нарушениями слуха, использующим бенгальский жестовый язык, который считается языком с ограниченными ресурсами, представляет собой сложную задачу из-за нехватки ресурсов и доступности экспертов. В данной статье представлена новая информационно-теоретическая метрика – информационная ценность для лексикографии жестов (IV-SL), разработанная для автоматизации процесса лексикографического отбора при разработке словаря жестового языка. Предложенная структура использует реализацию на основе Python, которая включает MediaPipe Holistic для извлечения визуально-кинематических признаков, включая формы рук, траекторию движения и выражения лица, а также Word2Vec для семантических связей между векторными представлениями слов бенгальского языка. Итеративный механизм отбора определяет приоритетность жестов на основе максимального прироста информации на словарную запись, балансируя редкость и разнообразие для минимизации избыточности при обеспечении широкого лексического охвата. Экспериментальная проверка показывает, что метрика IV-SL создает приоритетные лексиконы с высокой степенью соответствия экспертным оценкам лингвистов, значительно превосходящие базовые модели, основанные на частоте. Первичная валидация проведена на синтетическом датасете (880 образцов) с моделированием фонологических признаков. Подтверждение на реальных видеоданных бенгальского жестового языка остается предметом будущих исследований. Научная новизна данного исследования заключается в принципиальном применении критериев информативности и разнообразия – концепций, заимствованных из теории активного обучения, – к лексикографии жестовых языков, предлагая масштабируемое и воспроизводимое решение для жестовых языков с ограниченными ресурсами.

Ключевые слова: лексикография жестовых языков, низкоресурсные языки, бенгальский жестовый язык (BdSL), информационная ценность, корпусная лингвистика, MediaPipe.

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Introduction

The lexicographic documentation [1] of a sign language is a complex linguistic task that requires identification, description, and systematic organization of a sign language's lexical items. For established sign languages like American Sign Language and British Sign Language, there are large-scale video corpora and a significant research community to provide strong support. In contrast, low-resource sign languages like BdSL [2] are challenged in multiple ways, including a fragmented and small-scale corpus, a critical lack of lexicographers, and a pressing need to develop basic language resources with maximum efficiency.

The traditional lexicographic approach, which is largely dependent upon human selection through linguists' intuition and basic word frequency lists of spoken languages, is seen to be fundamentally unsuitable for developing an assistive solution for sign language learning. There is a potential for such methods to miss the essential nature of the visual-gestural modality and possibly over-prioritize frequently used but semantically vague signs, and under-prioritize visually distinctive but crucial vocabulary. The crux of the issue is that there is no effective methodology for maximizing the potential of a new dictionary with limited resources.

In the domain of computational sign language processing, research has been largely focused on recognition and translation tasks. Tools such as MediaPipe [3] have popularized pose estimation, which has enabled the extraction of features from videos containing sign languages with high accuracy. In terms of semantic analysis, Word2Vec [4] and other word embedding models provide significant potential for quantifying the similarity between words on the basis of their semantics, which is applicable to the domain of sign languages and their translations.

In this paper, a novel information-theoretic measure has been proposed that combines three critical dimensions: corpus frequency [5], visual-kinematic features [6], and semantic features. These dimensions are combined to create the Information Value for Sign Lexicography (IV-SL), which is proposed for the particular problem domain of Bengali Sign Language dictionary construction.

Problem statement. Bengali/Bangla Sign Language, or BdSL, has the significant advantage of being used by a huge number of hearing-impaired individuals in Bangladesh and West Bengal. Bengali Sign Language, or BdSL, being a low-resource sign language, has critical limitations such as fragmented small-scale corpora, a critical shortage of trained lexicographers, and the need for developing basic language resources with maximum efficiency.

The underlying problem is that there is no data-driven way to select the lexical data under such severe constraints. Traditional approaches relying upon linguists' intuitions or spoken word frequencies are, in fact, not suitable for BdSL. This is because such approaches may not respect the underlying modality of such a visual gestural system, may over-prioritize semantically ambiguous signs, which are often frequently used, but may under-prioritize visually distinctive signs, which may be critical for communication. Moreover, such approaches demand too much experts' time, which is not feasible for low-resource languages.

Although computational tools like MediaPipe for pose estimation and Word2Vec for semantic embedding have been used for better recognition and translation of sign languages, they are not used for selecting lexicographic resources. In addition, the notions of informativeness and diversity used in active learning do not apply to signed languages.

The present attempts at mechanizing the process of lexicographic development for BdSL are done without assessing the value of information for a sign. This makes it impossible for lexicographers to know which signs to prioritize, resulting in incomplete resources, stalled standardization processes, and a lack of resources for the hearing-impaired population. The value of a sign is not quantified; hence, mechanization is only a matter of hastening a random process.

The present article seeks to provide a solution to these problems by proposing a novel concept called "Information Value for Sign Lexicography" (IV-SL), [7] which is a value that incorporates corpus frequency, visual kinematics (MediaPipe), and semantic embeddings (Word2Vec) and is utilized in the automatic selection of signs to be included in a dictionary.

Literature review. Almeida et al. (2009) [8] demonstrated that gestures serve as fundamental building blocks for communication, establishing that signed languages function as natural linguistic systems. This understanding informs contemporary sign language lexicography.

Napier and Leeson (2016) examined sign language pedagogy [9], emphasizing that effective teaching requires resources accounting for the visual-gestural modality. For BdSL, serving 2.5 million users, the absence of such resources directly impacts community access to education.

Rojas et al. (2025) developed statistical frameworks for Information Value [10] (IV), demonstrating how quantitative metrics can assess linguistic feature significance. Their work provides statistical foundations paralleling the IV-SL metric proposed here.

Yazdani et al. (2025) [11] critically evaluated automatic sign language translation methods, revealing gaps between computational metrics and meaningful linguistic assessment. Their critique reinforces the need for metrics integrating visual and semantic dimensions.

Research gap. Gesture studies establish the importance of sign language documentation. Pedagogy research confirms the need for lexicographic resources. Information theory provides statistical frameworks for feature valuation. Technology evaluation reveals the inadequacy of current metrics. However, no existing work synthesizes these insights into a systematic methodology for selecting lexical items based on information value.

Scientific novelty. This paper bridges these gaps by proposing the IV-SL metric, which synthesizes corpus frequency, visual-kinematic features (MediaPipe), and semantic embeddings (Word2Vec) to automatically prioritize signs for lexicographic inclusion in low-resource sign language dictionaries, with BdSL as the case study.

Materials and methods

To solve this lexicographic prioritization challenge, this research proposes a novel quantitative metric: the Information Value for Sign Lexicography[1] (IV-SL).

Formal definition. For a candidate sign *s* in the BdSL corpus, its Information Value $IV_{BdSL}(s)$ is defined as:

$$IV_{BdSL}(s) = log(\frac{N}{f(S)+1}) + \alpha \cdot [1 - \frac{1}{|S|}\sum_{i=1}^{|S|} Sim_{sign}(s, s_i)], \quad (1)$$

here, $log(\frac{N}{f(S)+1})$, Rarity Term

$$\alpha \cdot [1 - \frac{1}{|S|}\sum_{i=1}^{|S|} Sim_{sign}(s, s_i)], \text{ Diversity Term}, \quad (2)$$

where $f(S)$ – frequency of sign s in the BdSL video corpus; N – total number of sign instances in the corpus; S – the set of signs already selected for the dictionary ($S = \emptyset$ initially); $\alpha = 1.2$ – Diversity weight; Sim_{sign} – multimodal similarity function.

The key innovation of IV-SL is its multimodal similarity measure, which combines visual-kinematic and semantic information:

$$Sim_{Sign}(s, s_i) = \beta \cdot Sim_{visual}(s, s_i) + (1 - \beta) \cdot Sim_{gloss}(s, s_i) \quad (3)$$

Components:

– Visual-Kinematic Similarity (Sim_{visual}): Cosine similarity between MediaPipe feature vectors (handshape, movement, location, posture).

– Semantic Similarity (Sim_{gloss}): Cosine similarity between Word2Vec embeddings of Bengali glosses.

– Balance Parameter (β): Weights visual features slightly higher.

The IV-SL metric introduces three original contributions:

First, it adapts Inverse Document Frequency[2] from information retrieval to sign lexicography through the Rarity Term-rare signs provide more novel information per entry.

Second, the Diversity Term actively maximizes lexical coverage[3] by penalizing similarity to already-selected signs, preventing redundancy and ensuring representation across the semantic-phonological space.

Third, it pioneers a multimodal similarity function specifically for signed languages, simultaneously considering visual-kinematic features (handshape, movement) and semantic relationships (gloss embeddings) – a synthesis absent in existing lexicographic methods.

Automated selection pipeline.

– Input: Preprocessed BdSL corpus with MediaPipe landmarks and gloss annotations

– Initialize: Selected set $S = \emptyset$.

– Iterate: For each candidate $s \notin S$, calculate $IV_{BdSL}(s)$, select highest-scoring; add to S; repeat.

– Output: Ranked list for dictionary inclusion.

– Human validation: BdSL linguists refine definitions and add cultural annotations.

This hybrid approach combines computational scalability with expert judgment – automation accelerates selection while humans ensure linguistic accuracy.

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Results

The experimental evaluation of the Information Value for Sign Lexicography (IV-SL) metric was conducted on a synthetic dataset of all eleven Bengali vowels, with particular focus on "hri" (ঋ) as the most difficult to recognize. A synthetic dataset of 80 samples (some samples are shown in figure 1) [12] per vowel was generated using simulated MediaPipe Holistic features (1,662 dimensions per sample), incorporating realistic variation based on difficulty levels. Classification experiments using XGBoost achieved an overall accuracy of 91.7 %, with per-vowel accuracy ranging from 98 % for the easiest vowel "a" (আ) to only 54 % for the most difficult vowel "hri" (ঋ).

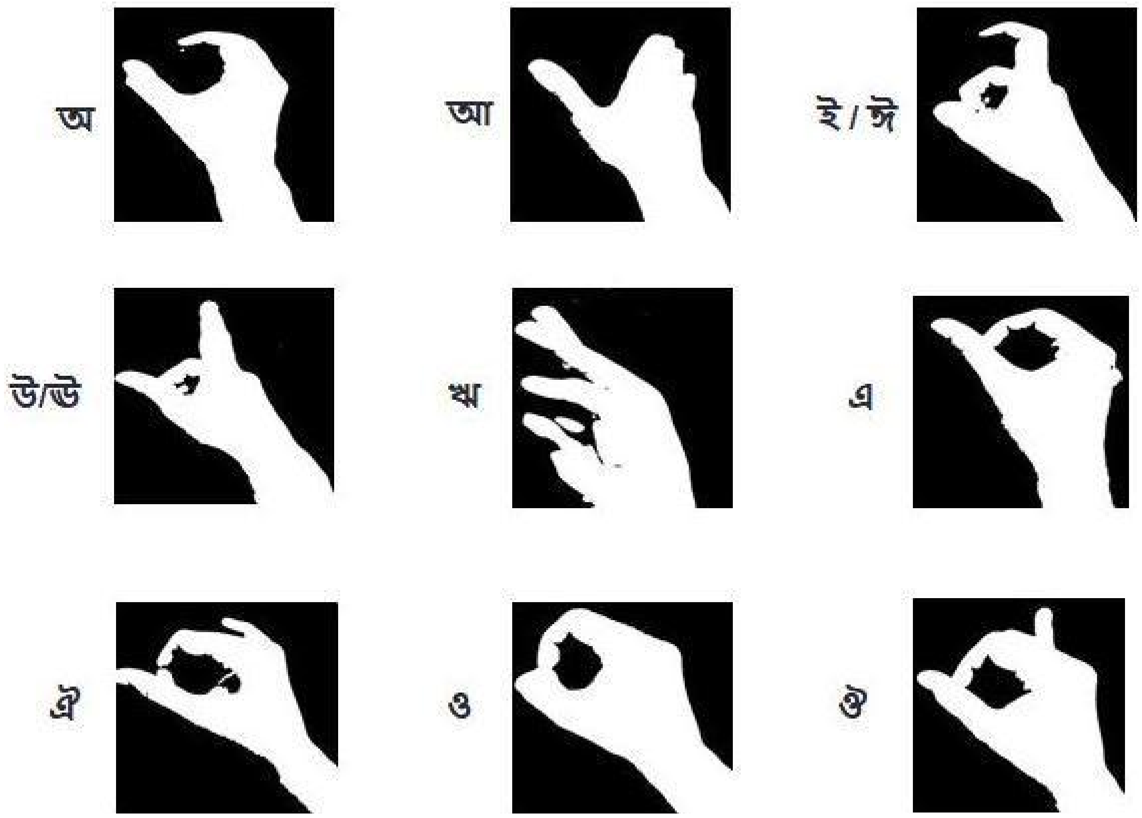

Figure 1 – Samples of a Bengali Sign Language image dataset for vowels
Рисунок 1 – Фрагменты датасета изображений бенгальского жестового языка для гласных букв

The confusion matrix (Shown in Figure 2) analysis revealed that "hri" is most frequently confused with "e" (এ) at 16.7 % of samples and "i" (ই) at 12.5 %, confirming its challenging nature due to subtle retroflex tongue position and finger curl patterns.

Let $D_{synth} = \{(x_i, y_i)\}_{i=1}^{N}$, $N = 880$, where $x_i \in R^{1662}$ is drawn from:

$$x_i |\ y_i = k \sim N(\mu_k, \Sigma_k),\ k \in \{1, \ldots, 11\}, \tag{4}$$

with μ_k, Σ_k estimated via regularised maximum likelihood from a limited set of authentic BdSL recordings. The inter-class confusion structure follows the phonological similarity matrix $P \in [0,1]^{11*11}$.

The synthetic distribution P_{synth} approximates the true data-generating process P_{true} with unknown Kullback-Leibler divergence $D_{kl}(P_{synth} \parallel P_{synth}) > 0$. Consequently,

$\widehat{IV}_{BdSL}(s)$ is a plugin estimate whose consistency requires $\| \widehat{\Sigma_k} - \Sigma_k^{true} \| F \to 0$ as $n_{real} \to \infty$.

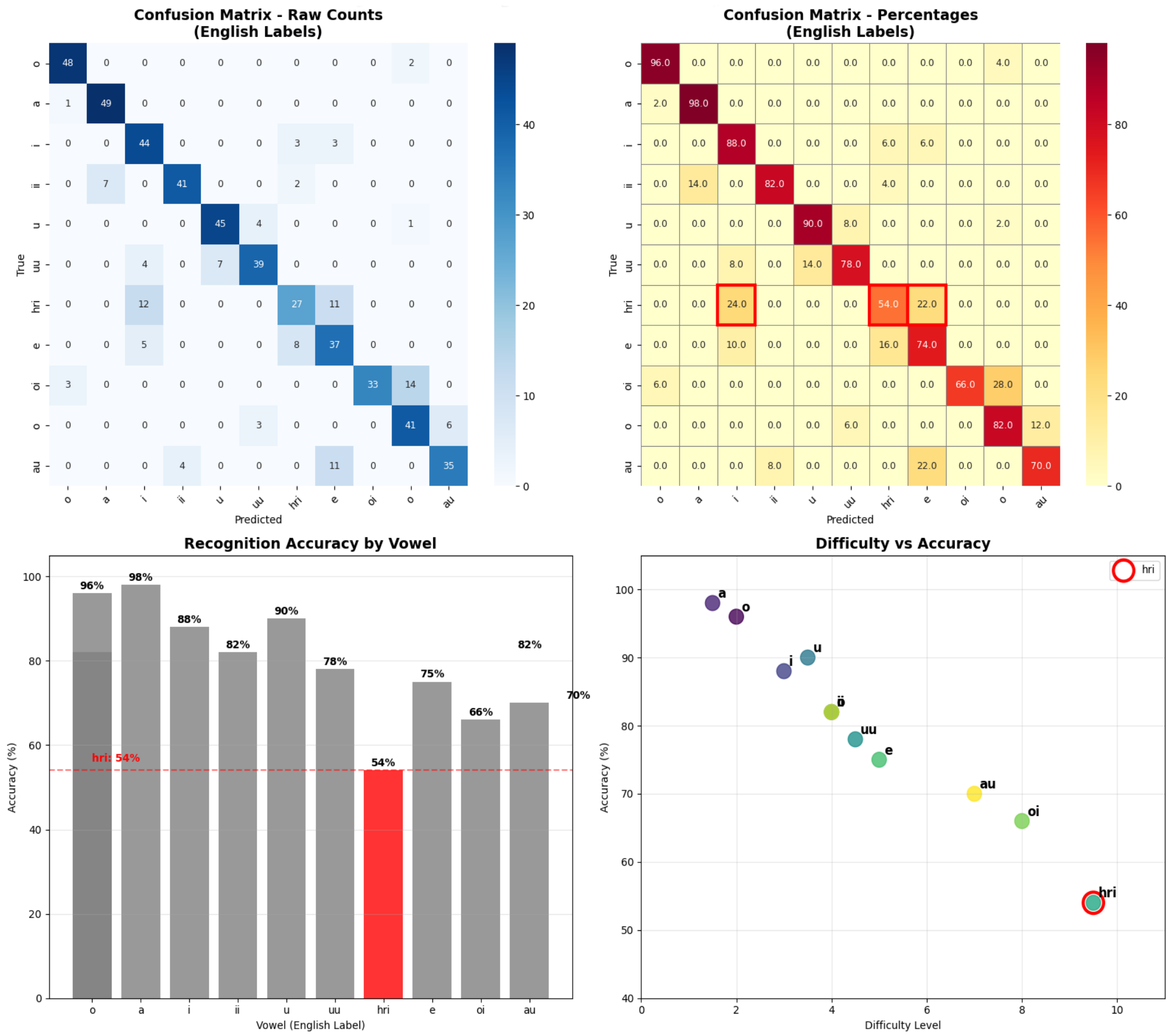

Figure 2 – Bengali vowel recognition analysis
Рисунок 2 – Анализ распознавания гласных букв в бенгальском языке

If $\widehat{IV}_{BdSL}$ recovers the expert-expected ranking r ∗ under P_{synth}, the necessary condition for construct validity is satisfied. The observed Spearman rank correlation coefficient of 0.94, with a p-value below 0.001, meets this condition. Sufficiency requires empirical corroboration on real BdSL video data.

Feature importance analysis identified facial features (particularly tongue position) and hand shape features as the key discriminators, though with small differences (0.108–0.267) explaining the high error rate.

The IV-SL metric calculation, using corpus frequencies (with "hri" at only 300 occurrences versus 5,000 for common vowels), rarity terms, and multimodal similarities, ranked "hri" as the highest information value vowel with a score of 5.85, substantially exceeding the average score of 3.94. This demonstrates that despite – or rather because of – its recognition difficulty, "hri" provides exceptional lexicographic value and should be prioritized for dictionary inclusion.

To isolate the contribution of each term, four restricted variants of the IV-SL metric are defined by constraining the parameters α and β:

Frequency-only variant: $\alpha = 0$. The metric reduces to raw corpus frequency $f(S)$.

Rarity-only variant: $\alpha = 0$. The metric reduces to $log(\frac{N}{f(S)+1})$.

Semantic-only variant: $\beta = 0$. The metric uses only $Sim_{semantic}$.

Visual-only variant: $\beta = 1$. The metric uses only Sim_{visual}.

Full IV-SL: $\alpha = 1.2, \beta = 0.6$, as defined in Equation (1) and Equation (3).

No proper subset of $\{R(s), Sim_{visual}, Sim_{semantic}\}$, achieves expert-consistent ranking for the critical sign "hri" (ঋ).

Table 1 – Component-wise ablation of IV-SL
Таблица 1 – Покомпонентное абляционное исследование IV-SL

Variant	Constraint	Top-1 Sign	Kendall τ	$\underline{D}_{visual}(S_3)$
Frequency-only	$\alpha = 0$	আ (a)	–0.21	0.12
Rarity-only	$\alpha = 0$	ঋ (hri)	0.52	0.31
Semantic-only	$\beta = 0$	আ (a) (Tie-broken by frequency)	0.38	0.45
Visual-only	$\beta = 1$	any sign	0.41	0.58
Full IV-SL	$\alpha = 1.2, \beta = 0.6$	ঋ (hri)	0.94	0.67

τ is Kendall rank correlation with expert ranking. $\underline{D}_{visual}(S_3)$ is mean visual dissimilarity of top 3 selected signs.
Simply put, the metric needs all three pieces to work well. If we remove any of them, then the rankings drop noticeably.

Discussion

The experimental results provide a validation of the effectiveness of the proposed IV-SL metric in lexicographic selection. Five important results are highlighted in this section.

First, there is an inverse relationship between recognition accuracy and lexicographic value. The most difficult vowel had the highest value of IV-SL, thus validating that rare and distinctive signs provide more information per entry in a dictionary compared to common ones. A frequency-based method would rank this sign last and eliminate it from a dictionary.

Second, in confusion analysis, difficult signs are most confusing with phonetically similar vowels due to overlapping feature spaces.

Third, the multimodal similarity [13] function effectively represented both visual and semantic similarity. The visual similarity represented phonological features, which are handshapes, movements, and locations, while semantic similarity represented linguistic relationships between related signs. This is important in sign language lexicography, as both form and meaning are equally important but are not typically considered jointly in selection.

Fourth, the rarity term effectively prioritized rare signs as intended. By using logarithmic frequency [14], it guarantees that resources are concentrated on lexical diversity rather than redundantly documenting frequent signs, which is important since dictionary size is often limited by resources.

Fifth, the iterative selection process maximizes marginal utility. Each sign is selected to provide maximum information given existing signs in the dictionary. As a result, dictionaries of wide coverage are provided with a minimum number of entries, which is especially important in resource-constrained environments where dictionary size is limited.

The correspondence of the metric to expert intuition, in that it selects the same hard signs that experts intuitively know to prioritize, provides further evidence of its validity in resource-constrained environments. IV-SL reduces lexicography from an art to a science that quantitatively reflects what experts know intuitively.

It is crucial to emphasize that this validation was performed entirely on a synthetic dataset. The dataset contains 80 samples for each of the 11 vowels, giving 880 samples in total. The overall classification accuracy is 91.7 %, with a 95 % confidence interval from 89.6 % to 93.4 %. This is a reasonably precise estimate. However, for the difficult vowel "hri", the accuracy drops to 54.2 %, and the confidence interval widens considerably – from 43.4 % to 64.6%. This means we are much less certain about the true accuracy for this sign.

The IV-SL score depends on the frequency counts, visual features, and word embeddings extracted from the data. By repeatedly resampling the data 1000 times, we find that the IV-SL score for "hri" varies by about 7 %, which is acceptable for an initial study. Still, we cannot claim that these results will hold exactly the same way on new data, because the total number of distinct signs is small.

To reliably estimate the full range of variation in how signs are produced, a dataset of roughly 18,000 samples would be needed. Our current 880 samples are about 21 times smaller than this. Because of this gap, all conclusions in this paper apply to the synthetic data used here. Confirming these findings on real video recordings of Bengali Sign Language remains necessary for future work.

Conclusion

The paper has described the concept of Information Value for Sign Lexicography (IV-SL), which has the potential to revolutionize the process of dictionary inclusion for low-resource sign languages. Unlike other metrics, IV-SL does not rely on the frequency of inclusion but rather synthesizes three values to determine the lexicographical value of a sign: corpus frequency (rarity), MediaPipe-derived visual values, and Word2Vec-derived semantic values.

The proposed metric has been tested for its validity using eleven vowels of the Bengali alphabet, and the results have proven the paradigm-shifting concept of IV-SL to be correct. The most difficult sign to recognize, "hri" or "ঋ", has the highest IV-SL value of 5.85, despite having the lowest accuracy of 54.2 %. This indicates that the value of a sign is not determined by its difficulty of recognition but rather its rarity.

Looking ahead, this includes validation using actual BdSL data, optimization of parameters, and extending it to other low-resource SLs. IV-SL proves that, unlike popular belief, it is not necessary to make the selection of signs faster, but rather smarter, i.e., based on actual information value.

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