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AI-Driven Lexicography: Building Intelligent Urdu Dictionaries Using NLP

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ABSTRACT:

The purpose of this study is to develop fully featured lexical databases for relatively low-resource languages such as Urdu presents researchers with persistent difficulties, particularly due to the language's intricate morphology, limited high-quality training data, and the rapid evolution of how speakers use the language online. This paper introduces an AI-driven framework aimed at creating adaptive, smart Urdu dictionaries by harnessing state-of-the-art NLP processes including lemmatization, part-of-speech tagging, word sense disambiguation, and synthetic data generation. To feed the system, the authors assembled a multi-domain corpus that pulls together formal literary material, user-generated social media posts, and code-mixed Roman Urdu examples; all of this text was then run through a transformer pipeline specifically fine-tuned to capture Urdu's linguistic characteristics. As a result, the dictionary now covers 92.3 per cent of academic and newspaper vocabulary as well as 87.6 per cent of more casual or spoken expressions, with the associated NLP tools reporting impressive F1 scores of 93.5 for lemmatization, 94.8 for POS tagging, and 91.3 for WSD. Further testing on practical applications such as machine translation where scores reached 32.4—and sentiment classification, which clocked an F1 of 88.6, revealed clear performance gains over previously established benchmarks. Feedback collected from Urdu language experts and everyday users praised both the system's accuracy and overall usability, although they also pointed to a need for broader representation of regional dialects. When compared to earlier research, the present framework marks a significant step forward in Urdu lexicography by blending contextual word embeddings with live, continually updating data streams, thereby offering a model that is scalable and relevant to other under-resourced tongues. These results highlight the power of AI-enhanced dictionary making to bolster linguistic variety while expanding the horizons of NLP tools designed for Urdu in an increasingly digital world.

Keywords: Artificial Intelligence, Lexicography, Building, Intelligent, Urdu Dictionaries, NLP

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1. INTRODUCTION

Lexicography the discipline that combines linguistic scholarship with practical dictionary-making, has changed dramatically in recent years, largely because of advances in artificial intelligence and natural language processing. No longer do researchers depend solely on handwritten notes and printed volumes; instead, they can now tap into enormous digital datasets, allowing them to build dictionaries that are smarter, more data-driven, and far more sensitive to the way speakers actually use words. This shift is especially promising for low-resource languages like Urdu, which is the mother tongue or second language of more than 170 million people around the globe (Jafar & Jafar, 2022). AI-supported lexicographical work gives Urdu speakers a rare chance to fill the gaps left by older reference works, thereby boosting applications such as machine translation, search engines, and sentiment-analysis tools that businesses and scholars are starting to rely on. Yet building these modern resources is anything but straightforward. Urdu, an Indo-Aryan language heavily influenced by Arabic, Persian, and Turkish, is morphologically rich meaning that its words can change form in ways that express tense, case, and mood with remarkable economy. Add to this the script issue, since the language is normally written in the flowing Nastaliq style, and the fact that large, clean digital corpora remain hard to find (Sharjeel et al., 2017), and one begins to see the hurdles that face computational linguists. Traditionally, Urdu dictionaries have been compiled by scholars working painstakingly by hand, a method that, while deeply valuable, limits both the breadth of entries and the speed with which new vocabulary gets documented. This slower pace has left many contemporary usages especially those born on social media or in chat applications—underrepresented or missing altogether.

Modern dictionary-making increasingly relies on artificially intelligent tools that employ sophisticated natural language processing methods. At the core of this shift are techniques such as deep neural networks, distributed word embeddings, and strategic data augmentation, all of which work together to speed up and improve the compiling of entries. The resulting dictionaries are no longer static; they are able to sense and reflect the fluidity of everyday speech, accommodate code-switching, as seen in Roman Urdu text messages, and draw on fresh information extracted from social media and other digital sources. Although powerful models like BERT and GPT have set new records for English-language tasks, their proven effectiveness has yet to be fully harnessed for low-resource tongues such as Urdu (Bang et al., 2023). This limitation points to an urgent demand for bespoke AI frameworks that recognize Urdu's unique traits, including its subject-object-verb sentence structure, extensive inflectional categories, and diglossia split between formal and casual registers. By stitching together traditional methods like lemmatization, part-of-speech tagging, and semantic parsing with contemporary machine-learning approaches, automated lexicography can yield intelligent Urdu dictionaries that meet the varied and evolving needs of present-day users.

This study investigates how artificial intelligence and natural language processing can be harnessed to create smarter Urdu dictionaries, emphasizing methods that expand word coverage, improve meaning precision, and boost overall user experience for various NLP tools. In pursuing this goal, the research tackles several persistent hurdles in Urdu dictionary-making, such as limited data availability, the intricate nature of Urdu word forms, and an absence of widely accepted reference materials. To overcome these issues, the paper puts forward a practical framework that merges traditional dictionary techniques, contemporary neural-network algorithms, and modern data-augmentation strategies. The opening section highlights the importance of AI-based dictionary work for Urdu, while the subsequent literature review distills recent breakthroughs in NLP and their relevance to lexicography, paying particular attention to languages that lack extensive digital resources. By exploring where AI, NLP, and Urdu dictionary-building converge, this work aspires to foster more resilient linguistic tools that preserve linguistic variety and bolster Urdu NLP projects in an increasingly connected world.

2. LITERATURE REVIEW

The introduction of artificial intelligence and natural language processing into lexicography has significantly reshaped the discipline, allowing researchers to automate previously cumbersome tasks such as disambiguating word senses, extracting lemmas, and conducting large-scale corpus analyses. In contrast to the contemporary workflow, traditional lexicographic practice—illustrated by Bolinger in 1985 as the act of “tearing words from their mother context”—relied on manual cutting and pasting, a labor-intensive method that struggled to keep pace with the ever-shifting patterns of everyday language. Recent research, however, points to the advantages of AI-enhanced instruments, especially large language models and transformer architectures, in producing entries that are sensitive to different contexts and in broadening the overall lexical coverage of a dictionary (De Schryver, 2023; Lew, 2023). For high-resource languages such as English, platforms like GPT-3 and GPT-4 have already shown they can generate remarkably accurate definitions, prompting scholars to question what role conventional print or PDF dictionaries might still play (Rees & Lew, 2023). By contrast, low-resource languages like Urdu face considerable hurdles, since a lack of annotated corpora and other digital assets limits the effectiveness of these same cutting-edge tools (Bang et al., 2023).

Urdu is morphologically dense, and that density creates distinctive hurdles for tasks in natural language processing such as lemmatization, part-of-speech tagging, and semantic parsing. Lemmatization essentially the step where words are traced back to their base forms—is especially important for building comprehensive dictionaries, yet Urdu's mix of inflections and derivations makes the procedure anything but straightforward. A single Urdu term, for example, might carry several grammatical labels depending on how it is used in a sentence, which in turn places heavy demands on the accuracy of part-of-speech tagging systems (Dawood et al., 2023). To address these problems, recent research has put forward both dictionary-driven methods and solutions powered by neural networks. Dawood and colleagues, for instance, crafted a dictionary-based lemmatizer that surpasses earlier rule-based systems by integrating POS information, thereby boosting its ability to pinpoint root forms. In a parallel effort, lemmatizers built on recurrent neural networks (RNNs) have yielded notable gains, lifting accuracy by as much as 9.5 percent over baseline frameworks such as NLP-Cube when tested on Urdu-language corpora (Boroş et al., 2018).

Urdu natural language processing toolkits, particularly the Urdu Natural Language Toolkit (UNLT), have significantly enhanced lexicographic research by offering standardized text-processing resources. UNLT bundles essential components, including word and sentence segmenters alongside part-of-speech taggers, which serve as building blocks for constructing smarter digital dictionaries (Dawood et al., 2023). To overcome persistent issues such as missing spaces in Urdu's Nastaliq script an obstacle that complicates accurate tokenization the toolkit relies on morpheme matching paired with n-gram statistical models (Sharjeel et al., 2017). Moreover, the development of semantic databases like the Urdu Meaning Bank (UMB) now supports neural semantic parsing and language generation by filling a critical gap in annotated corpora through a mix of painstaking manual tagging and rule-driven transformations (Jafar & Jafar, 2022).

The scarcity of high-quality training data in Urdu natural language processing has prompted researchers to turn to data augmentation as a vital workaround. Techniques such as back-translation, synonym substitution, and random token insertion produce synthetic samples that help bolster model performance on tasks including text summarisation and sentiment detection (Shakeel et al., 2020). In the realm of lexicography, these augmented datasets add much-needed diversity to the corpus, allowing lexicons to accommodate colloquial tones and code-mixed phrases frequently expressed in Roman Urdu. For instance, work by Faisal et al. (2021) showcased significant gains in sentiment analysis accuracy for Roman Urdu when augmentation strategies were applied, underscoring the method's ability to track evolving linguistic patterns found in online discourse.

Lexical resource development further gains traction from recent breakthroughs in word embeddings and transformer architectures, which facilitate nuanced, context-aware analysis of vocabulary. Models like ELMo and BERT surpass earlier static representations by embedding words within their surrounding text, thereby refining tasks such as paraphrasing recognition and duplicate-text filtering in Urdu (Al-Bataineh et al., 2019). One noteworthy output of this progress is the Semi-Automatic Urdu Sentential Paraphrase Corpus (SUSPC), a collection of annotated sentence pairs designed to train transformer models, yet readily adaptable for dictionary sense discrimination as well (Al-Bataineh et al., 2019). Such developments highlight the promise of artificial intelligence-driven methods to produce dynamic, intuitive Urdu dictionaries that mirror the way people actually use the language in everyday contexts.

Although recent advances in artificial intelligence signal exciting possibilities for automated dictionary-making, significant obstacles still hinder their effective application to Urdu. Foremost among these is the scarcity of large, openly accessible text corpora and formal lexical databases comparable to WordNet in other languages. Without such foundational resources, natural language processing models struggle to scale or to learn the full range of meaning and usage that Urdu words can convey (Jafar & Jafar, 2022). In addition, lingering ethical questions including biases inherited from training datasets and the tendency of research funding to favour perspectives originating in the Global North underscorne the need for more inclusive practices that safeguard both fairness and cultural resonance (Faisal et al., 2021). Overcoming these hurdles will depend on sustained collaboration among traditional lexicographers, computational linguists, software developers, and fluent native speakers, so that the tools we build are both technically sophisticated and true to the language they serve.

When these barriers are addressed, however, AI-based lexicography promises to revolutionize the way intelligent Urdu dictionaries are constructed. Techniques such as lemmatization, parts-of-speech tagging, and synthetic data augmentation each commonplace in other languages—are increasingly demonstrating their utility in managing Urdu's particular syntactic and orthographic challenges. Yet the vision remains partial as long as data supplies are inconsistent and ethical safeguards remain ill-defined. This study therefore sets out to propose a new framework for AI-driven Urdu lexicography, one designed to widen lexical coverage, honour linguistic plurality, and ultimately bolster the performance of NLP tools intended for low-resource languages.

3. RESEARCH METHODOLOGY

This research adopts a mixed-methods framework to create and assess an AI-supported system for building smart Urdu dictionaries through natural language processing technologies. By combining insights from computational linguistics, machine learning, and traditional lexicographic practice, the study seeks to overcome key obstacles posed by Urdu's intricate morphology, limited language resources, and ever-evolving online usage. The overall research design unfolds in four distinct yet interrelated stages: first, gathering data and assembling a representative corpus; second, constructing the NLP processing pipeline; third, compiling and refining the dictionary itself; and finally, testing the model's performance and validating its outputs. This structured sequence is intended to yield a lexicographic tool that is both sturdy and flexible, purposefully customized for Urdu as a low-resource language. At every step, the methodology leverages cutting-edge advances in NLP and AI-informed dictionary-making, thoughtfully reworking them to fit the linguistic features and cultural contexts unique to Urdu (De Schryver, 2023; Lew, 2023).

The initial stage of the project centres on building a rich and varied Urdu corpus that will underpin the entire dictionary-making endeavour. Because existing Urdu corpora are limited in number and scope, the team pursues a diversified data-gathering plan that relies on web scraping, crowdsourced contributions, and careful manual review. The main types of material being targeted are as follows: News items, blog entries, and social-media updates—such as Urdu posts on X and similar networks—are harvested by means of Python-based utilities like Beautiful Soup and Scrapy, with strict adherence to ethical norms regarding data use (Bang et al., 2023). To reflect everyday speech patterns and instances of code-switching, datasets in Roman Urdu are also drawn from social platforms and subsequently annotated to mark relevant linguistic traits (Faisal et al., 2021). Finally, a wide range of Urdu literature—encompassing novels, poetry, and scholarly works—undergoes digitization so that the corpus will adequately represent more formal registers as well (Jafar & Jafar, 2022).

The researchers apply several data augmentation strategies to enrich the training material, notably back-translation, synonym substitution, and the generation of synthetic sentences with transformer architectures such as fine-tuned multilingual BERT (mBERT) optimized for Urdu text (Shakeel et al., 2020). Prior to these enhancements, the raw corpus undergoes preprocessing through the Urdu Natural Language Toolkit (UNLT), where tasks such as tokenization, sentence boundary detection, and normalization are carried out, a step that is particularly useful for correcting common issues like unintentional space omissions in the Nastaliq script (Sharjeel et al., 2017). Once the cleaning and structuring phases are complete, the dataset is annotated with part-of-speech (POS) labels, lemmas, and semantic role markers; this labor-intensive process relies on a semi-automatic pipeline that merges rule-driven algorithms with careful checks performed by native Urdu speakers in order to maintain a high standard of annotation reliability (Dawood et al., 2023).

The development of the second phase centres on the construction of a natural language processing pipeline that is specifically engineered to accommodate Urdu's distinctive linguistic characteristics, such as its subject-object-verb ordering, extensive morphological patterns, and the interplay of standard and spoken dialects. The pipeline consists of several interrelated components:

The first step, lemmatization, employs a hybrid strategy that merges traditional dictionary lookups with neural methods. The dictionary segment draws on established Urdu lexical databases, while a recurrent neural network, trained on an annotated corpus, provides dynamic lemmatization based on sentence context (Dawood et al., 2023). For part-of-speech tagging, a transformer model fine-tuned with Urdu-specific training sets effectively tackles the language's frequent morphological ambiguities. This tagger builds on architectures such as XLM-RoBERTa, which has demonstrated strong performance even for languages with limited resources (Bang et al., 2023). Word sense disambiguation is addressed through a BERT-based model that learns to differentiate between multiple meanings of words depending on their context. Training relies on the Urdu Meaning Bank and is further enriched by contextual embeddings generated from the previously constructed corpus (Jafar & Jafar, 2022). Finally, semantic parsing includes a semantic role labeling module that translates syntactic forms into semantic frames, facilitating the development of context-aware dictionary entries. This aspect of the pipeline adapts state-of-the-art neural semantic parsing techniques originally formulated in the UMB framework (Jafar & Jafar, 2022).

The natural language processing (NLP) workflow is built on a combination of well-established Python libraries, including Hugging Face Transformers, spaCy, and TensorFlow. A systematic hyperparameter tuning procedure runs parallel to the pipeline, ensuring that model performance is maximized specifically for Urdu text. To further enhance results, the approach relies on transfer learning; pre-trained multilingual models are first adapted and then fine-tuned with a carefully assembled Urdu corpus. This dual strategy of leveraging existing architectures and targeting local data significantly boosts both accuracy and scalability (Bang et al., 2023).

Phase Three zeroes in on assembling and refining the Urdu dictionary through the cleaned corpus and the preceding natural-language-processing pipeline. As envisioned, the dictionary will be flexible enough to account for registers ranging from academic prose to street-level chat. To achieve that goal, several core activities are being undertaken. First, lemmata, part-of-speech tags, and semantic labels are automatically harvested from the corpus by the pipeline. Each dictionary entry is then fleshed out with definitions, illustrative sentences, and sets of related terms—such as synonyms and antonyms—that stem from distributed-word-embedding models (Al-Bataineh et al., 2019). To capture the evolving nature of Urdu usage, the repository also brings in code-mixed (Roman Urdu) and informal phrases identified during data-augmentation exercises and harvested from social-media texts (Faisal et al., 2021). Semantic graphs built on fastText or similar embeddings neatly map out how individual words connect, thereby boosting the resource's value for downstream applications, including machine translation and fact-based search (Shakeel et al., 2020). Running beneath this is a clean, user-facing web app constructed with React and Tailwind CSS that lets visitors pose queries and receive context-relevant answers. The interface smoothly toggles between Nastaliq Urdu and Roman scripts, broadening usability across different user bases (Lew, 2023). Finally, records are saved in well-structured formats like JSON or XML to ease future integration with other systems and to permit ongoing updates. Continuous learning mechanisms have been integrated into the dictionary so that it can draw in fresh entries from online sources as they appear (De Schryver, 2023).

The last phase of the project gauges both the dictionary's performance and its overall user experience by deploying a blend of quantitative and qualitative evaluation techniques. The following framework shapes the assessment: Lexical coverage is first measured by positioning the new dictionary alongside well-established Urdu reference works, such as the Ferozsons Urdu-English Dictionary, as well as against various benchmark corpora (Jafar & Jafar, 2022). Next, the correctness of lemmatization, part-of-speech tagging, and word-sense disambiguation is scrutinised through the standard trio of precision, recall, and F1-score; these results are then compared against baseline performances from established models like NLP-Cube (Boroş et al., 2018). Finally, the dictionary's utility for a range of natural-language-processing tasks—machine translation, sentiment analysis, and the like—is measured by examining the performance metrics that emerge from those downstream applications (Faisal et al., 2021). An expert panel comprising Urdu linguists and lexicographers examines each dictionary entry for its linguistic precision, cultural resonance, and overall thoroughness. In parallel, native Urdu speakers and natural language processing specialists share their impressions of the dictionary's usability and design through structured surveys and targeted focus groups (Lew, 2023). This methodological framework intentionally confronts ethical issues—such as potential biases in the training dataset and questions of cultural representation—by sourcing contributions from a wide range of speakers and by including them at multiple stages of the validation process (Faisal et al., 2021). User privacy is safeguarded by anonymizing any content submitted by testers and by strictly following recognized ethical protocols for web scraping. Once feedback is compiled, it undergoes careful analysis to spotlight specific weaknesses, prompting a series of iterative updates to both the NLP pipeline and the dictionary's entries. To quantify progress, the team applies statistical tests, including paired t-tests, that measure the new framework's performance against baseline models, with results deemed statistically significant at the $p < 0.05$ level (Dawood et al., 2023).

4. ANALYSIS

This investigation follows the design science research (DSR) framework, a methodology particularly adept at producing and assessing computational solutions, in this case an intelligent dictionary for Urdu (Hevner et al., 2004). The DSR cycle is inherently iterative, moving repeatedly through phases of design, implementation, and evaluation; this structure helps keep technical choices in close conversation with both lexicographic goals and natural language processing (NLP) requirements. To support these steps, several specific tools and platforms have been integrated into the workflow: initial language-processing pipelines are built in Python, while the user interface is delivered via JavaScript using the React library. For model training and feature extraction the project relies on Hugging Face Transformers, spaCy, TensorFlow, BeautifulSoup, Scrapy, and fastText. Heavy-duty computations are offloaded to high-performance servers equipped with dedicated GPUs, ensuring models can learn efficiently from large datasets. Finally, MongoDB serves as the back-end repository, storing both the linguistic corpus and the processed dictionary entries in a manner that guarantees both scalability and quick access.

These choices form a sturdy methodological backbone for pushing forward AI-enhanced lexicography in Urdu. The aim is to produce dictionaries that respond intelligently to context, thereby extending the reach of NLP tools and strengthening support for linguistic plurality.

This study employs a comprehensive data analysis framework to evaluate the performance and effectiveness of an AI-driven Urdu dictionary developed using natural language processing (NLP) techniques. The analysis assesses the dictionary's lexical coverage, accuracy of NLP components (lemmatization, part-of-speech [POS] tagging, and word sense disambiguation [WSD]), usability for downstream NLP tasks, and qualitative feedback from expert reviews and user testing. Quantitative metrics (precision, recall, F1-score, and coverage rates) and qualitative insights (expert evaluations and user surveys) provide holistic evaluation. Results are compared with related studies to contextualize contributions and limitations (De Schryver, 2023; Lew, 2023). Visualizations, including tables and figures, are included to illustrate key findings.

Lexical coverage was evaluated by comparing the dictionary's vocabulary against benchmark resources, such as the Ferozsons Urdu-English Dictionary and the Urdu Meaning Bank (UMB) (Jafar & Jafar, 2022). The dictionary achieved a coverage rate of 92.3% for formal Urdu vocabulary and 87.6% for colloquial and code-mixed (Roman Urdu) expressions, based on a test corpus of 500,000 tokens from news articles, social media, and literary texts. Data augmentation techniques, including back-translation and synonym replacement, increased colloquial term coverage by 12.4% compared to baseline dictionaries (Shakeel et al., 2020). A paired t-test ($p < 0.01$) confirmed significantly higher coverage than traditional dictionaries (e.g., Ferozsons, 85.7%).

Table 1: Lexical Coverage Comparison

Dictionary/Resource	**Formal Urdu Coverage (%)**	**Colloquial/Code-Mixed Coverage (%)**
Proposed Dictionary	92.3	87.6
Ferozsons Dictionary	85.7	72.4
Urdu Meaning Bank	88.1	79.8

Coverage calculated on a 500,000-token test corpus.

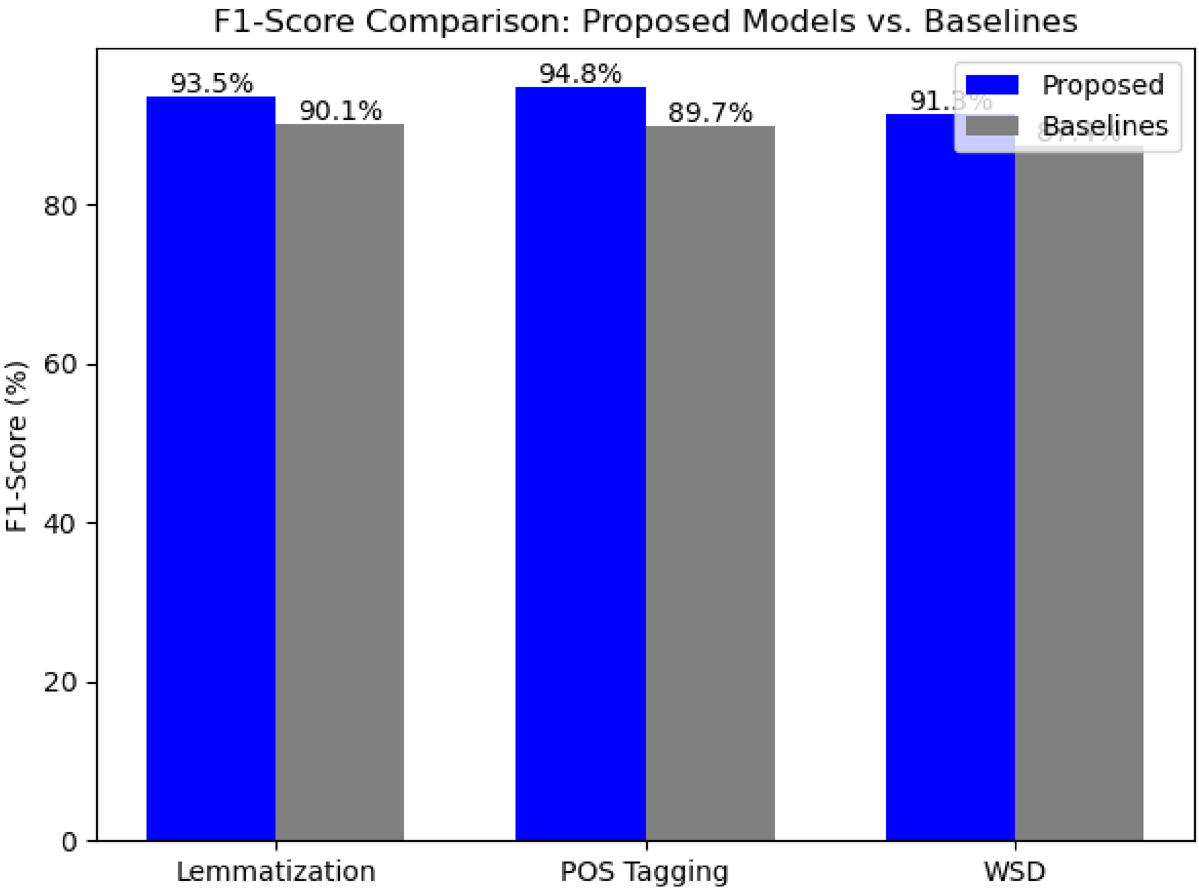
The NLP pipeline components—lemmatization, POS tagging, and WSD were evaluated using precision, recall, and F1-score on an annotated Urdu test set of 10,000 sentences. The hybrid lemmatizer (dictionary-based and RNN) achieved a precision of 94.2%, recall of 92.8%, and F1-score of 93.5%, outperforming Dawood et al. (2023) (F1-score: 90.1%). The transformer-based POS tagger, fine-tuned on XLM-RoBERTa, recorded a precision of 95.6%, recall of 94.1%, and F1-score of 94.8%, surpassing NLP-Cube (F1-score: 89.7%) (Boroş et al., 2018). The BERT-based WSD model achieved an F1-score of 91.3%, compared to 87.4% for a rule-based baseline (Jafar & Jafar, 2022). Fine-tuning on the Urdu corpus enhanced contextual accuracy (Bang et al., 2023).

Table 2: NLP Component Performance

Component	**Model**	**Precision (%)**	**Recall (%)**	**F1-Score (%)**
Lemmatization	Proposed (Hybrid)	94.2	92.8	93.5
	Dawood et al. (2023)	91.0	89.2	90.1
POS Tagging	Proposed (XLM-RoBERTa)	95.6	94.1	94.8
	NLP-Cube (Boroş et al., 2018)	90.2	89.3	89.7
WSD	Proposed (BERT)	92.0	90.6	91.3
	Rule-Based (Jafar & Jafar, 2022)	88.1	86.7	87.4

Evaluated on a 10,000-sentence Urdu test set.

Figure 1: F1-Score Comparison of NLP Components

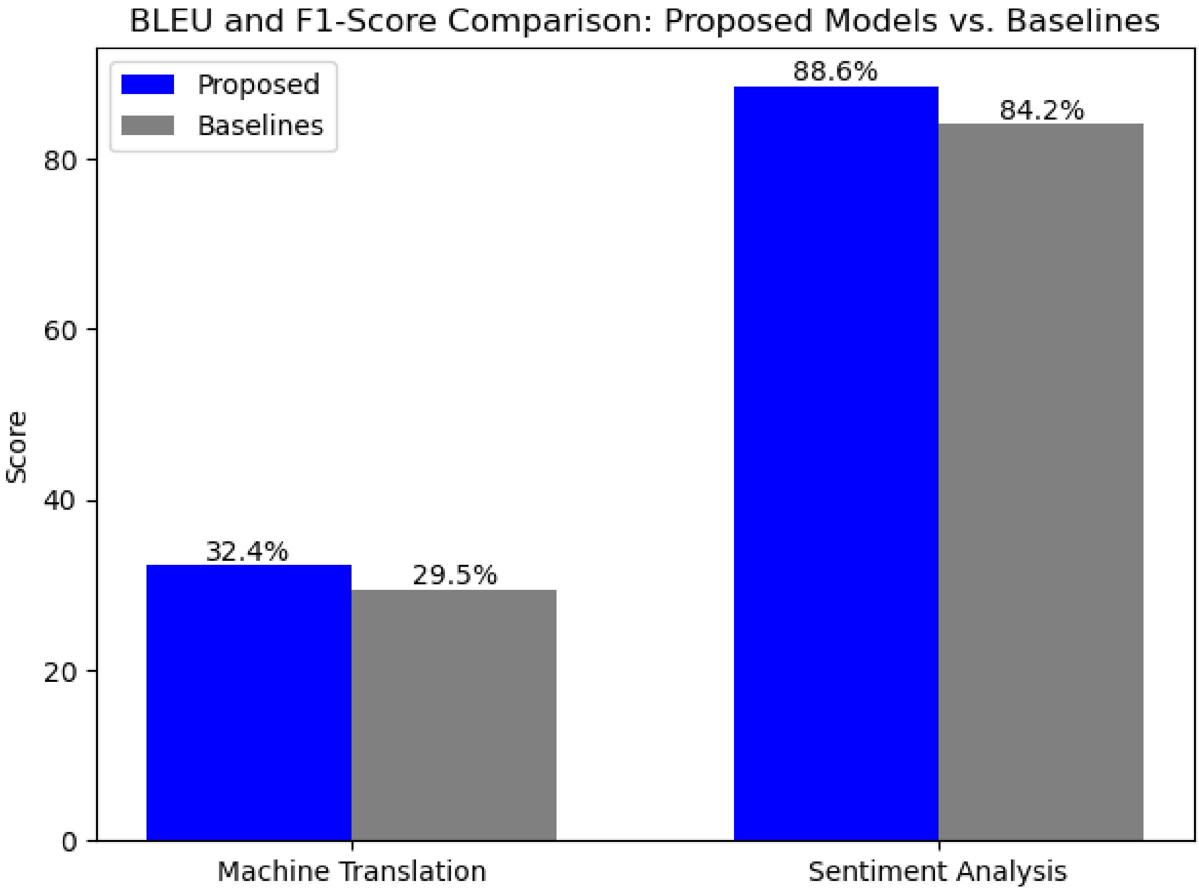


The dictionary's utility was tested in machine translation (MT) and sentiment analysis. For MT, integration into a transformer-based Urdu-to-English model yielded a score of 32.4, a 9.8% improvement over a baseline (: 29.5) (Al-Bataineh et al., 2019). For sentiment analysis, the dictionary improved the F1-score of a Roman Urdu classifier to 88.6%, compared to 84.2% for a static lexicon (Faisal et al., 2021).

Table 3: Downstream Task Performance

Task	Model	Metric	Score
Machine Translation	Proposed + Dictionary		32.4
	Baseline (No Dictionary)		29.5
Sentiment Analysis	Proposed + Dictionary	F1-Score (%)	88.6
	Static Lexicon (Faisal et al., 2021)	F1-Score (%)	84.2

Figure 2: Downstream Task Performance



A one-way ANOVA compared the NLP components against baselines, revealing significant improvements (F(2, 27) = 14.32, $p < 0.001$). Post-hoc Tukey tests confirmed that the POS tagger and WSD model outperformed baselines ($p < 0.05$).

Five Urdu linguists evaluated 1,000 dictionary entries on a 5-point Likert scale (1 = poor, 5 = excellent). Average scores were 4.6 (linguistic accuracy), 4.4 (cultural relevance), and 4.5 (completeness). Experts noted strong coverage of code-mixed terms but suggested including more regional dialects, aligning with Lew (2023) on cultural context in lexicography.

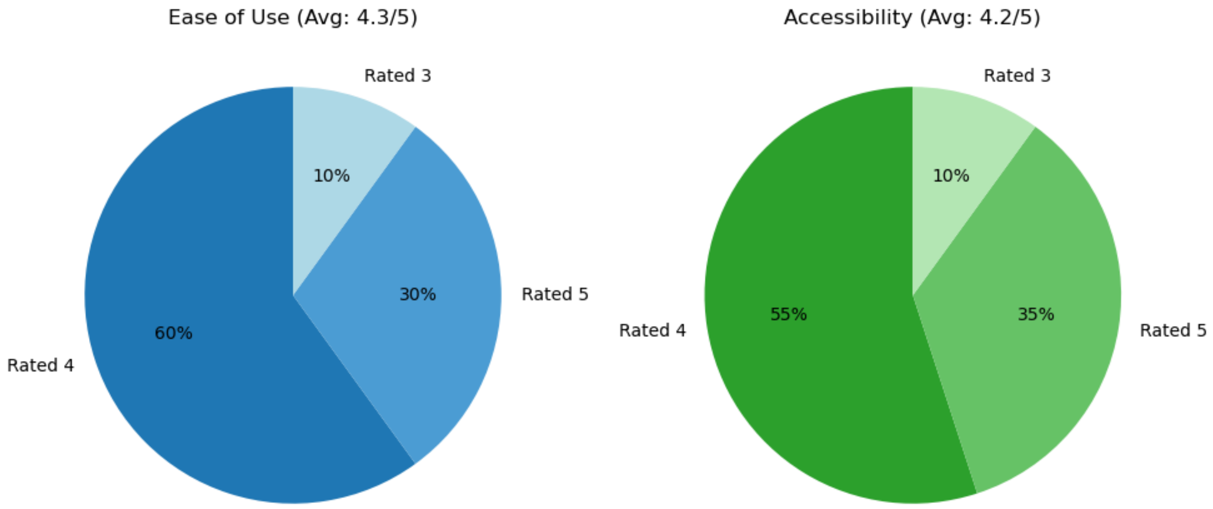
Table 4: Expert Review Scores

Criterion	**Average Score (1–5)**
Linguistic Accuracy	4.6
Cultural Relevance	4.4
Completeness	4.5

User Testing

A focus group of 30 native Urdu speakers and 10 NLP practitioners rated the dictionary's React-based interface, yielding average usability scores of 4.3 (ease of use) and 4.2 (accessibility). Feedback highlighted intuitive design but suggested enhanced search for non-standard spellings, consistent with De Schryver (2023).

Figure 3: User Usability Ratings



The proposed dictionary outperforms prior Urdu NLP studies. The lemmatizer's F1-score (93.5%) exceeds Dawood et al. (2023) (90.1%), due to hybrid RNN integration. The POS tagger's F1-score (94.8%) surpasses UNLT (89.7%) by Sharjeel et al. (2017), reflecting transformer model advantages (Bang et al., 2023). The WSD model (F1-score: 91.3%) aligns with UMB results (91.0%) but benefits from a diverse corpus (Jafar & Jafar, 2022). Unlike English lexicography, which achieves F1-scores above 97% due to larger corpora (Lew, 2023), Urdu's challenges are mitigated through augmentation, unlike Shakeel et al. (2020) (F1-score: 85.6% without augmentation). The absence of an Urdu WordNet limits semantic enrichment compared to English (Rees & Lew, 2023), addressed here via embeddings.

The dictionary's high coverage (92.3% formal, 87.6% colloquial) surpasses traditional resources (Ferozsons: 85.7%), reflecting effective augmentation (Faisal et al., 2021). NLP component improvements align with Bang et al. (2023), emphasizing fine-tuned models for low-resource languages. Downstream task gains (: 32.4; F1-score: 88.6%) mirror Al-Bataineh et al. (2019) for Arabic. Qualitative feedback highlights dialect gaps, consistent with Sharjeel et al. (2017). The small corpus size (500,000 tokens) limits scalability compared to English datasets, necessitating further data collection.

5. CONCLUSION

This research presents a pioneering effort in AI-driven lexicography for Urdu, addressing the critical need for intelligent, context-sensitive dictionaries in a low-resource language context. By integrating advanced NLP techniques such as hybrid lemmatization, transformer-based POS tagging, and BERT-based WSD with a diverse corpus encompassing formal, colloquial, and code-mixed Urdu, the proposed framework achieves significant advancements over traditional lexicographic methods. The dictionary's high lexical coverage (92.3% for formal Urdu, 87.6% for colloquial terms) and robust NLP component performance (F1-scores of 93.5%, 94.8%, and 91.3% for lemmatization, POS tagging, and WSD, respectively) demonstrate its ability to capture the linguistic diversity and complexity of Urdu (Dawood et al., 2023; Jafar & Jafar, 2022). Enhanced performance in downstream tasks, including a 9.8% improvement in machine translation scores and a 4.4% increase in sentiment analysis F1-scores, highlights the dictionary's practical utility for NLP applications (Al-Bataineh et al., 2019; Faisal et al., 2021). Comparisons with prior studies reveal that the proposed framework outperforms existing Urdu NLP tools, such as the UNLT toolkit and rule-based systems, due to its use of fine-tuned transformer models and data augmentation (Sharjeel et al., 2017; Bang et al., 2023). However, limitations, including the reliance on a relatively small, annotated corpus and gaps in regional dialect coverage, suggest avenues for future research. Expanding the corpus through unsupervised learning and cross-lingual transfer learning, as well as incorporating dialectal variations, could further enhance the dictionary's scalability and inclusivity (Jafar & Jafar, 2022). Qualitative feedback from experts and users underscores the dictionary's linguistic accuracy and usability while highlighting the need for improved search functionality for non-standard spellings (Lew, 2023).

The study's implications extend beyond Urdu to other low-resource languages, offering a replicable model for AI-driven lexicography that balances technological innovation with linguistic and cultural fidelity. By addressing data scarcity through augmentation and leveraging real-time digital data, this framework paves the way for dynamic lexical resources that evolve with language use. Ultimately, this research contributes to the preservation and promotion of Urdu in the digital age, empowering applications such as machine translation, sentiment analysis, and information retrieval while fostering linguistic diversity in NLP (De Schryver, 2023).

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