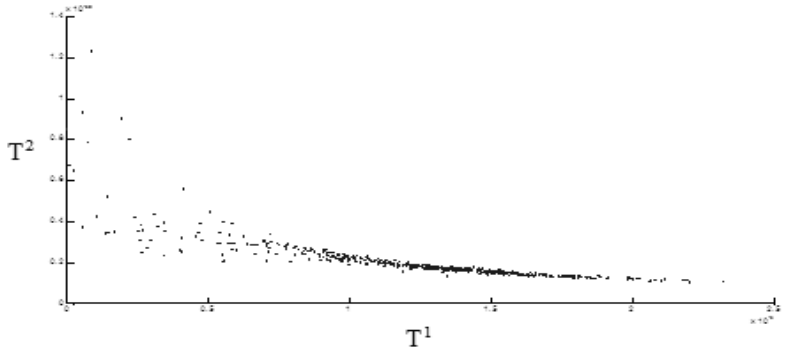


Fig. 8. Distribution of 500 feature vectors written by 500 different writers in Hindi text.

In the first experiment (Experiment I), we used 100 samples (1 sample per writer) for training and tested it on the 200 remaining samples (2 samples per writer). In the second experiment (Experiment II) we trained the system on 200 samples (2 samples per writer) and tested it on 100 samples (1 sample per writer). In the third experiment (Experiment III) all 300 samples were used as a training set and we tested the system on this set as shown in Table 5. All of the experiments used the KNN [35] classification scheme.

Table 5. Experimental setup

Experiment	Training samples	Test sample
I	100	200
II	200	100
III	300	300

The results show that the features using the structures of base line direction, slant, interline spacing, margin, average upper mid ratio, and all seven features as shown in Table 4 yielded 100% perfect results in Experiment III in both scripts, whereas, recognition accuracy decreased in other two experiments. However, Experiment II yielded better results than Experiment I in all of the cases. This is due to the training set size. We observed an 88% and 89% correct identification rate when we experimented with Experiment II, and a maximum of 75% and 77% in terms of recognition accuracy in an experiment with Experiment I samples on Devnagari and Latin script. Moreover, these results indicate that the structural features of baseline, slant, inter-line spacing, margins, and average upper mid ratio are good features for writer identification. However, features that yielding poor results can also be used in conjunction with the best performing features for assessing a writer's personality. In an attempt to improve the writer obtained using the five best performance features of baseline direction, slant, margins, average upper identification accuracy of Experiment II, we applied a majority voting [32] scheme to results that we mid ratio, and all seven features as shown in Table 4. The majority voting classifier rejected the conflicting samples (having no majority or a tie). Thereby, in this case, the identification accuracy was improved. The majority voting increased its accuracy to 97% (in both languages) at the expense of an 8% and 10% rejection rate in Hindi and English text, respectively.

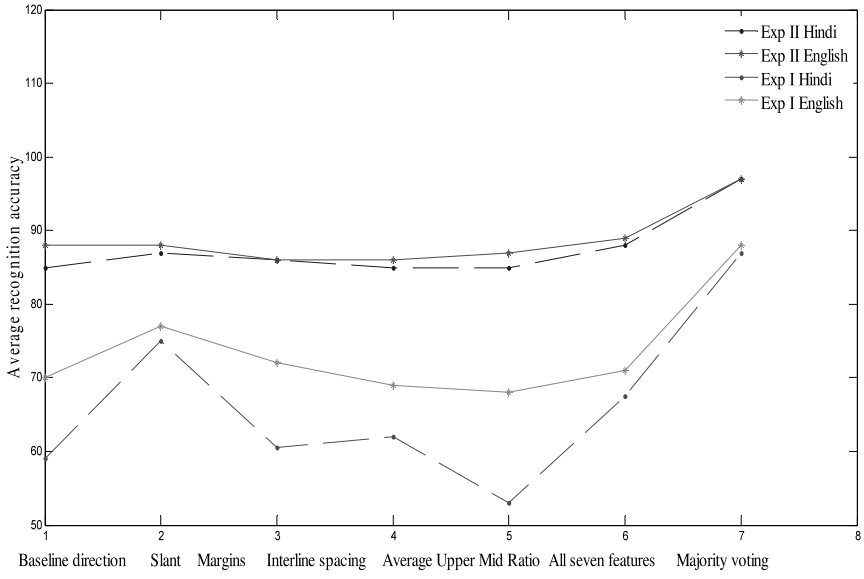
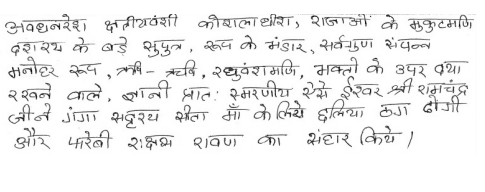
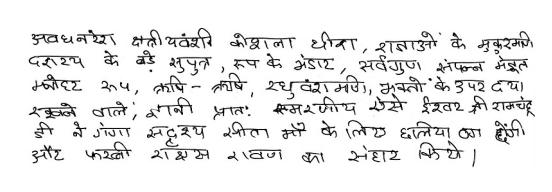


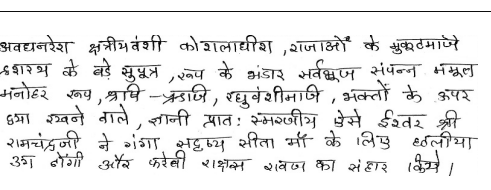
Fig. 9. Performance comparision of Hindi and English handwritten text in Experiments I and II.

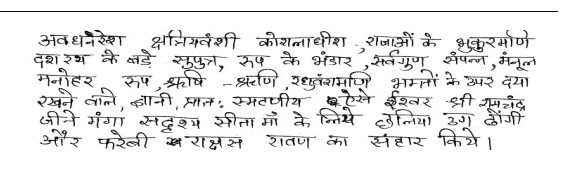
We also observed that the overall performance of writer identification in Latin script is better than Devnagari script, as shown in Fig. 9. As seen in this figure, it is clear that the slant feature yielded the highest recognition accuracy in both scripts, from among all the individual features. As seen in Fig. 9, it is also clear that recognition accuracy in the case of English test is more than that of Hindi text in all of the experiments. The substituted samples are shown in Table 6.

Table 6. Handwriting samples of misclassified writer









6. Conclusions

This paper reports on the development of a handwriting biometric based person identification system. The major contributions of this paper are that it use the following items: 1) defined structural properties from graphologists and handwriting experts; 2) fuzzy subsets that use structural linguistic variables described by handwriting experts; and 3) estimates of fuzzy membership values as feature values. In addition to fuzzy based writer identification, we designed a Devnagari pangram to collect the

benchmark dataset and test the performance of the system. The system yielded 100% accuracy on the training set, with a maximum of 97% and 88% accuracies on the test set with and without the rejection of handwriting samples, respectively. These results are very encouraging, and provide incentives for augmenting the system with personality assessment system and other handwriting analysis based applications by developing a knowledge-based system using expert's knowledge on the association of handwriting structures with traits, and representing these traits by fuzzy rules. However, these experiments are based on fundamental features, as used by handwriting experts. Writing style and its graphic features are not included in this system. Since the *Sirorekha* of the word(s) is used to estimate the orientation of the entire text, there is the chance that the handwritten *Sirorekha* can lead to disorientation. This influences the overall estimation of the mood of writer. A possible solution for this can be using individual character alignment along with *Sirorekha* for a better orientation that can help improve the performance of a system.

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