Brute force matching of binary image feature descriptors is conventionally performed using the Hamming distance. This paper assesses the use of alternative metrics in order to see whether they can produce feature correspondences that yield more accurate homography matrices. Two statistical tests, namely ANOVA (Analysis of Variance) and McNemar’s test were employed for evaluation. Results show that Jackard-Needham and Dice metrics can display better performance for some descriptors. Yet, these performance differences were not found to be statistically significant.

Distance metrics: Considering two binary descriptors to be matched as two binary sequences, the following four dependent quantities are defined as:

\[
\begin{align*}
  f_{00} & : \text{num. of positions where both descriptors have 0s,} \\
  f_{01} & : \text{num. of positions where the first has 0 and the second has a 1,} \\
  f_{10} & : \text{num. of positions where the first has 1 and the second has a 0,} \\
  f_{11} & : \text{num. of positions where both descriptors have 1s.}
\end{align*}
\]

Using these quantities, the following distance metrics used for evaluation are defined: \(d_H\) for Hamming distance, \(d_J\) for Jaccard-Needham, \(d_C\) for correlation, \(d_D\) for Dice and \(d_Y\) for Yule distance metric. These are given by the literature [6, 7] as follows:

\[
\begin{align*}
  d_H &= \frac{f_{11} + f_{00}}{f_{00} + f_{10} + f_{11}} \\
  d_J &= \frac{f_{11}}{f_{11} + f_{01} + f_{10} + f_{11}} \\
  d_C &= \frac{f_{11} f_{00} - f_{10} f_{01}}{\frac{f_{11} f_{00} + f_{10} f_{01}}{2}} \\
  d_D &= \frac{2 f_{11} f_{00} + f_{10} f_{01}}{f_{11} f_{00} + f_{10} f_{01}} \\
  d_Y &= \frac{f_{11} f_{00} + f_{10} f_{01}}{f_{11} f_{00} + f_{10} f_{01} + f_{10} f_{01} + f_{11} f_{00}}
\end{align*}
\]

where \(\sigma = \sqrt{(f_{10} + f_{11}) (f_{00} + f_{01}) (f_{10} + f_{01}) (f_{00} + f_{11})}\). These various metrics, widely used in data mining applications, are employed here in order to assess the accuracy of the homography matrix calculated using them.

Evaluation: The main question of this evaluation is first modelled in a null hypothesis framework (two-way ANOVA with image pairs and distance metrics as the two independent variables). Here, the null hypothesis states that there are no differences between the accuracies of the homography matrices calculated using the correspondences found when various metrics are employed, given the same set of keypoints. The alternative hypothesis states that there will be differences if different metrics are used for matching these binary descriptors. Further analysis is performed using McNemar’s test to identify pairwise differences.

In order to quantify the accuracy of the calculated homography matrices, this evaluation employed the following approach depicted in Fig. 1. First image features are extracted using the detector part of ORB (5000 keypoints were extracted in order to provide good coverage [5]). These keypoints, with computed descriptors (e.g. BRIEF, BRISK), are matched across a pair of images. Using these matches, a homography matrix is calculated and applied to the first image in order to warp it onto the second. Here, an intermediate image is calculated (\(d_1\)) which is then subtracted from the second image in order to remove the non-overlapping part (\(d_2\)). Finally, the result image (\(d_3\)) is obtained as the difference between warped version of the first image and \(d_2\). The evaluation criterion is chosen as the sum of non-zero pixels of \(d_3\). A larger sum indicates accuracy problems in the homography matrix resulting in alignment issues.

It is important to reiterate that the evaluation here focuses only on the selection of the distance metric for finding a correspondence, not for evaluating different descriptors. However, descriptors were varied in type and size (e.g. BRIEF 32 and 64 bits) in order to see how this was affecting the results.

Using the sums of remaining pixels (samples for this evaluation) obtained from a dataset of 388 image pairs (all pairwise combinations) from a publicly available dataset\(^1\) we applied a logarithmic transformation to the samples in order to reduce variance.

Results: Initial results from the samples (Fig. 2) show some differences across the various metrics and descriptor types. In order to see whether these differences are statistically significant or not, ANOVA was employed (Table 1). Analysis showed that different metrics have an effect on the results and the test confirms that there are significant differences (\(F > F_{crit}\) for all descriptor types). Furthermore, the P-value shows that the confidence on these results is very high.

Having found the differences, the next step is to identify the distance metric which is producing better results in terms of the accuracy of calculated homography matrix. McNemar’s test was employed for this purpose allowing pairwise comparisons between different metrics using z-scores. A value of 0 indicates no difference in performance, while 2.576
Fig. 2 Effect of distance metric for different feature descriptors. Means bar indicate the mean performance of the metric in various descriptors.

Table 1: Results for the ANOVA test

| Source of Variation | df | MS   | F    | P-value | F crit |
|---------------------|----|------|------|---------|--------|
| BRIEF32             |    |      |      |         |        |
| Image pairs         | 287| 26.26| 46.53| 0.00    | 1.16   |
| Metrics             | 4  | 0.30 |      | 0.00    | 2.38   |
| Error               | 1148|      |      | 0.00    | 2.38   |
| BRIEF64             |    |      |      |         |        |
| Image pairs         | 287| 42.51|      | 0.00    | 1.16   |
| Metrics             | 4  | 0.30 |      | 0.00    | 2.38   |
| Error               | 1148|      |      | 0.00    | 2.38   |
| BRISK               |    |      |      |         |        |
| Image pairs         | 287| 134.53|     | 0.00    | 1.16   |
| Metrics             | 4  | 0.30 |      | 0.00    | 2.38   |
| Error               | 1148|      |      | 0.00    | 2.38   |
| ORB                 |    |      |      |         |        |
| Image pairs         | 287| 154.47|     | 0.00    | 1.16   |
| Metrics             | 4  | 0.30 |      | 0.00    | 2.38   |
| Error               | 1148|      |      | 0.00    | 2.38   |

indicates 99.5% confidence in one-tailed prediction meaning that one metric is statistically better than the other. Looking at the results of Table 1, it can be seen that Yule displayed the worst performance of all the metrics for different descriptors. For BRISK and ORB descriptors, Jaccard-Needham has surpassed the Hamming distance; however, the difference was not statistically significant. Comparing this result with that of Fig. 2 on average, there are metrics that perform better than the Hamming distance, but this did not manifest itself significantly in a statistical evaluation.

Table 2: Results for the McNemar’s test. Arrow-heads point to the metric resulting in a better accuracy.

| Metric   | Jaccard-Needham | Correlation | Dice | Yule  |
|----------|-----------------|-------------|------|-------|
| BRIEF32  |                 |             |      |       |
| Hamming  | ← 0.84          | ← 0.71      | ← 0.84| ← 7.60|
| Jaccard-Needham | ← 0.07      | 0.00        | ← 7.72|
| Correlation| ↑ 0.07         | ↑ 0.07      | ← 7.72|
| Dice     | ← 7.72          | ← 7.72      |       |       |
| BRIEF64  |                 |             |      |       |
| Hamming  | ← 1.30          | ← 0.45      | ← 1.30| ← 4.30|
| Jaccard-Needham | 0.00           | 0.00        | ← 4.42|
| Correlation| 0.00           | ↑ 1.11      | ← 10.70|
| Dice     | ← 4.42          | ← 4.42      |       |       |
| BRISK    |                 |             |      |       |
| Hamming  | ↑ 0.71          | ↑ 0.97      | ↑ 0.71| ← 9.40|
| Jaccard-Needham | ← 1.11      | 0.00        | ← 10.70|
| Correlation| ↑ 1.11         | ↑ 1.11      | ← 10.11|
| Dice     | ← 10.70         | ← 10.70     |       |       |
| ORB      |                 |             |      |       |
| Hamming  | ↑ 0.52          | ↑ 1.56      | ↑ 0.52| ← 5.86|
| Jaccard-Needham | ← 0.13      | 0.00        | ← 6.34|
| Correlation| ↑ 0.13         | ↑ 0.13      | ← 5.98|
| Dice     | ← 6.34          | ← 6.34      |       |       |

Conclusion: This paper presented an evaluation in order to see whether distance metrics other than the conventional Hamming distance can be used for matching binary image feature descriptors. Results revealed that there are, indeed, metrics resulting in a more accurate homography matrix, producing less difference when the first image is warped onto the second. Findings also showed that these differences did not reflect well in a statistical evaluation, i.e. no significant differences were found.

E. Bostanci (Computer Engineering Department, Ankara University, Turkey)
E-mail: ebostan@ankara.edu.tr

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Considering the options provided by modern processor instruction sets for implementing the Hamming distance, it keeps its position to be the metric of choice for brute force matching of binary descriptors.