

A GENDER RECOGNITION EXPERIMENT ON THE CASIA GAIT DATABASE DEALING WITH ITS IMBALANCED NATURE

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Abstract: The CASIA Gait Database is one of the most used benchmarks for gait analysis among the few non-small-size datasets available. It is composed of gait sequences of 124 subjects, which are unequally distributed, comprising 31 women and 93 men. This imbalanced situation could correspond to some real contexts where men are in the majority, for example, a sports stadium or a factory. Learning from imbalanced scenarios usually requires suitable methodologies and performance metrics capable of managing and explaining biased results. Nevertheless, most of the reported experiments using the CASIA Gait Database in gender recognition tasks limit their analysis to global results obtained from reduced subsets, thus avoiding having to deal with the original setting. This paper uses a methodology to gain an insight into the discriminative capacity of the whole CASIA Gait Database for gender recognition under its imbalanced condition. The classification results are expected to be more reliable than those reported in previous papers.

1 INTRODUCTION

The perception of gender determines social interactions. Humans are very accurate at recognizing gender from a face, a voice or the manner in which an individual walks (*gait*). Nevertheless, in comparison to a voice or a face, gait can be perceived at a greater distance. This particular issue has stirred up the interest of the computer vision community in creating gait-based gender recognition systems. In recent years, this matter has become a hot research area in the computer vision field (Yu et al., 2009; Li et al., 2008; Huang and Wang, 2007). A number of applications can benefit from the development of such systems, for example, demographic analysis of a population, access control, biometric systems, etc.

Apart from being successfully captured at a distance, gait has additional advantages with regard to other biometric features: it is non-contact, non-invasive and, in general, does not require subjects' willingness. Nevertheless, there are important drawbacks that make the implementation of a gait-based gender classification system a hard challenge. For instance, gait analysis is very sensitive to deficient or incomplete segmentation of the subject silhouette, to variations in clothing and/or footwear, to distortions in the gait pattern produced by carrying objects or by

changes of mood, to walking speed, and so forth.

These sources of complexity have contributed to the lack of public databases with a moderate or large number of gait samples with enough diversity, and also to the limited usefulness of the research done up until now. Some of the few non-small-size datasets available for benchmark purposes are listed in Table 1. All of them are unequally distributed in terms of the number of men and women, and they take into account some covariates that affect the manner of walk (viewpoint changes, footwear and clothing changes, walking surface changes, carrying conditions, etc).

In this work, the CASIA Gait Database (CASIA, 2005) is studied due to its availability and completeness. Some works (Yu et al., 2009; Huang and Wang, 2007; Lee and Grimson, 2002) have used this database for gender recognition tasks. However, their experiments have been formulated on the basis of small subsets with an equal number of subjects per class, giving results greatly dependent on singularities of the subsets. In addition, they measured the classification performance in terms of global accuracy, ignoring individual class error rates and possible biased behaviours of the classifiers. Such practices make it impossible to evaluate the potential of the CASIA Gait Database for gender recognition purposes considering its true distribution and number of samples. This pa-

Table 1: Non-small-size gait databases.

<i>Name</i>	<i>#Subjects</i>	<i>#Men</i>	<i>#Women</i>	<i>#Sequences</i>
USF HumanID Gait Database (Sarkar et al., 2005)	122	85	37	1870
Soton Gait Large Database (Shutler et al., 2002)	100	84	16	2128
CASIA Gait Database (CASIA, 2005) - Dataset B	124	93	31	13640

per proposes a methodology to gain an insight into the discriminative capacity of the whole CASIA Gait Database for gender recognition. The classification model consists of an ensemble of classifiers that suitably deal with the imbalance of the training data. The classification results, in terms of suitable performance measures, are expected to be more reliable than those reported in previous papers.

2 PREVIOUS WORK

There is a lot of research related to gait-based identification, but only a few recent works use gait for gender recognition. There are two different approaches to describe gait: i) *dynamic features* from subjects' movements (Davis and Gao, 2004; Yoo et al., 2005), and ii) *static attributes* from the subject's appearance (Lee and Grimson, 2002; Huang and Wang, 2007; Yu et al., 2009), which implicitly contain information about his/her movements. The closer related works to this paper lie in the last approach and are described below.

In (Lee and Grimson, 2002), static features that describe the silhouette appearance of a human walking are used for person identification and gender recognition. A segmentation process was applied to video frames in order to extract human silhouettes, which were then normalized regarding size and location. To represent appearance, human silhouettes were divided into seven regions that were fitted with ellipses. To represent movement (changes in silhouette poses across the frames), some parameters of the ellipses that model the same region are averaged across all the frames of a sequence, resulting in a set of 57 attributes per sequence. Classification experiments on the MIT Gait Database (MIT, 2001) lead to an accuracy close to 80%.

A closely related work was presented in (Huang and Wang, 2007), where the same research methodology of (Lee and Grimson, 2002) was applied to a part of the CASIA Database. A classification accuracy of 85% was obtained from averaging 200 runs with different pairs of training and test sets. From the 124 subjects (93 men and 31 women) available, 25 women and 25 men were randomly selected for each training set, while another 5 women and 5 men were chosen for the corresponding test set. Apart from the previ-

ous result, this work proposes an information fusion experiment in which decisions were based on three different points of view: front, back and side view. The gender recognition rate of the fusion scheme was 89.5%, which was higher than those results obtained from the individual views.

Another recent study (Yu et al., 2009) proposed a different appearance-based method for gait-based gender recognition that was tested on the CASIA Gait Database. Given a sequence of gait silhouettes, a Gait Energy Image (GEI) is created by combining them. The GEI is divided into 5 regions, head/hairstyle, chest, back, waist/buttocks and legs, which are weighted as regards a previous psychological study. Experiments involved a single subset composed of 31 women and 31 randomly selected men that fed a Support Vector Machine with a linear kernel. The best classification result was an accuracy of 95.97%. Nevertheless, the use of only one subset raises doubts about the reliability of the result, because of its dependence on the subset singularities.

3 METHODOLOGY

This paper proposes a methodology to gain an insight into the discriminative capacity of the CASIA Gait Database for gender recognition, considering all of its samples (31 women and 93 men). The experimental design involves all the samples in contrast to some previous works (Huang and Wang, 2007; Yu et al., 2009), where only reduced subsets composed of an equal number of samples per gender were used.

The methodology has four main supports:

- Feature extraction: as in (Lee and Grimson, 2002), the average values across all frames of a gait sequence of some parameters of seven ellipses that fit silhouette regions are used.
- Performance measures: this work uses well-known unbiased measures to evaluate the classification effectiveness in imbalanced contexts.
- Classification model: an ensemble of classifiers is proposed to manage the data imbalance.
- Evaluation of the classifier error: It is estimated by a 10-fold cross validation repeated 10 times.

The next subsections provide details of each of the four items introduced above.

3.1 Feature Extraction

For feature extraction, the ellipse-fitting method presented in (Lee and Grimson, 2002) was used due to the preliminary nature of this paper and the simplicity of this method. In addition, it is also referenced in the other two works (Huang and Wang, 2007; Yu et al., 2009) that are the main works in which this paper is based on. The process proposed in (Lee and Grimson, 2002) includes the following steps, as was introduced in the previous section:

Foreground Segmentation. Each gait sample of the CASIA Gait Database includes the gait video sequence and the corresponding set of frames with the foreground segmented from the background. These frames, where the silhouettes are highlighted, are used directly in order to make this proposal more appropriate to be a benchmark for future comparisons.

Silhouette Extraction. The bounding box that encloses all the silhouette pixels is located, and the resulting reduced image is extracted.

Silhouette Regionalization. The silhouette is divided into seven regions with fixed proportions: head, chest, back, front thigh, rear thigh, front calf/foot and rear calf/foot.

Ellipse Fitting. The shape of the foreground pixels of each region is fitted with an ellipse. For details, see Figure 1.

Feature Extraction. Four features per ellipse are extracted: the x and y -coordinates of the centroid, the orientation of the major axis (α) and the aspect ratio ($axis_1/axis_2$). An extra global feature, which consists of the quotient of the y -coordinate of the silhouette centroid to the silhouette height, is also considered.

Gait Representation. To represent the gait video sample (changes in silhouette poses across the frames), the mean and the standard deviation of the four parameters of each ellipse are computed across all the frames of the sequence. The eight resulting features of each of the seven ellipses are concatenated, along with the mean of the extra global feature, to build a 57-dimensional vector.

3.2 Performance Measures for Imbalanced Data Sets

A typical metric for measuring the effectiveness of a learning process is the accuracy of the resulting

classifier over a test or validation set. For a two-class problem, this index can be easily computed from a 2×2 confusion matrix defined by the *True Positive* (TP) and *True Negative* (TN) cases, which are the numbers of positive and negative samples correctly classified, respectively, and the *False Positive* (FP) and *False Negative* (FN) cases, which are the numbers of negative and positive samples incorrectly classified, respectively. Accuracy is formulated as $Acc = (TP + TN)/(TP + FN + TN + FP)$.

However, empirical evidence shows that this measure can be strongly biased with respect to class imbalance (Provost and Fawcett, 1997). This shortcoming has motivated the search for new measures suitable for imbalanced contexts, for example, (i) *True Positive rate* $TPr = TP/(TP + FN)$; (ii) *True Negative rate* $TNr = TN/(TN + FP)$; (iii) *Geometric mean* $Gmean = \sqrt{TPr * TNr}$, that chooses models in which both accuracies are high and balanced; and (iv) *Area Under the ROC Curve* (AUC), which can be computed as $AUC = (TPr + TNr)/2$ for a single classification result.

In this paper, TPr, TNr, Gmean and AUC are computed along with Accuracy to provide enough per-class knowledge of the classifier performance.

3.3 Classification Model

The classification model consists of an ensemble of classifiers that can suitably deal with the imbalance of the training data (Kang and Cho, 2006).

Given an imbalanced two-class training set, a number of balanced subsets equal to the number of base classifiers of the ensemble are generated. Each subset contains all samples of the minority class and as many randomly selected samples of the majority class as were needed to obtain a balanced subset. The ensemble combines, by majority voting, the individual decisions of base classifiers trained with the corresponding balanced subsets. For details, see Figure 2.

In a gait-based gender recognition task, where each person is usually represented by several sequences of gait frames, the previous process of subset generation can be performed in two ways. The first way is to balance the subset *at person level*, which means that the same number of women and men are randomly selected, and all their sequences joined to form a new subset. It is worth noting that this subset may not be exactly balanced with respect to the number of sequences of each gender. The alternative is to balance *at sequence level*, which refers to the arbitrary selection of an equal number of sequences from each gender. Under this approach, the number of different subjects represented in the subset by at least one

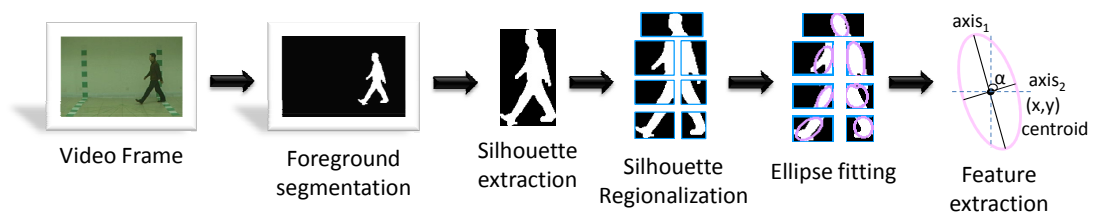


Figure 1: Feature extraction process.

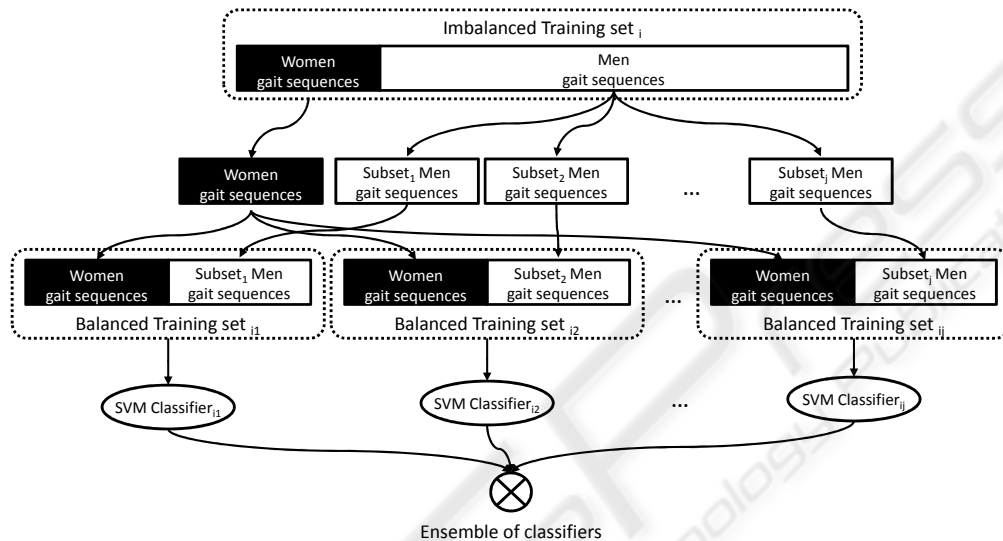


Figure 2: Generation of an ensemble of SVM classifiers.

sequence is, in general, much greater than that number in the strategy at person level. In this paper, both means of balance are implemented.

3.4 Error Evaluation Scheme

A 10-fold cross validation scheme that was repeated 10 times was used to estimate the recognition rates. The application of a stratified division method resulted in pairs of training and test partitions with distributions of samples per class similar to those of the original dataset. Each imbalanced training subset was used to feed an ensemble of classifiers described in Section 3.3, which later performed a classification session on the corresponding test subset. Algorithm 1 provides details of this process.

4 EXPERIMENTAL RESULTS

The aim of the experiments is to find out the actual capacity of the CASIA Gait Database for gender recognition from side-view gait sequences. From the 124 people available, distributed into 31 women and 93

men, the gait sequences corresponding to the subject identified as 005 (a man) were discarded due to their low number of frames with foreground information and their intractable noise. From the remaining 123 subjects, and the 6 side-view sequences per individual, a collection of 738 sequences was created with 186 and 552 samples from women and men, respectively. Each sample was represented by a 57-dimensional vector, as explained in Section 3.1.

Classification results are estimated by repeating (10 times) a 10-fold cross validation scheme, which involves an ensemble of 25 Support Vector Machines (SVM) for managing the imbalance of the training data. The number of classifiers chosen was 25 for two reasons: i) 25 is an odd number, which avoids ties, and ii) there is empirical evidence that more than about 25 base classifiers does not provide, in general, significant improvements to the ensemble accuracy (Bauer and Kohavi, 1999).

Three different experiments were designed.

Baseline. The imbalance is ignored and, thus, not treated. The 10-fold cross validation uses a single SVM (not an ensemble) fed by the imbalanced training partitions (see Sections 3.3 and 3.4).

Algorithm 1. Training/Classification algorithm.

```

for all training fold  $Tra_i$  ( $i \in 1, 10$ ) do
  for all classifier  $C_{ij}$  in ensemble ( $j \in 1, 25$ ) do
     $womenSubset_{ij} \leftarrow$  all sequences of all women
    from  $Tra_i$ 
    if balancing at person level then
       $menSubset_{ij} \leftarrow$  all sequences of a number
      of randomly selected men equal to the num-
      ber of women from  $Tra_i$ 
    else if balancing at sequence level then
       $menSubset_{ij} \leftarrow$  a number of randomly se-
      lected men sequences equal to the number
      of women sequences from  $Tra_i$ 
    end if
     $Balanced_{ij} \leftarrow womenSubset_{ij} \cup menSubset_{ij}$ 
    Train  $C_{ij}$  with  $Balanced_{ij}$ 
  end for

  for all  $sample_{ik}$  in  $Test_i$  ( $k \in 1, |Test_i|$ ) do
    for all trained classifier  $C_{ij}$  in ensemble do
       $predLabel_{ikj} \leftarrow$  Classify  $sample_{ik}$  on  $C_{ij}$ 
    end for
     $predLabel_{ik} \leftarrow$  Combine all  $predLabel_{ikj}$  by
    majority voting
    Compare  $predLabel_{ik}$  with  $actualLabel_{ik}$  for
    performance measures
  end for
end for

```

Balanced Classes at Sequence Level. The imbalance is managed. The 10-fold cross validation performs with an ensemble of 25 SVM that learn from balanced subsets at *sequence* level, randomly drawn from the imbalanced training partitions (see Sections 3.3 and 3.4).

Balanced Classes at Person Level. The imbalance is managed. The 10-fold cross validation performs with an ensemble of 25 SVM that learn from balanced subsets at *person* level, randomly drawn from the imbalanced training partitions (see Sections 3.3 and 3.4).

The main difference between the second and third experiment is that the number of men represented in the balanced subsets by at least one sequence is, in general, quite a lot higher in the second than in the third, although the number of men sequences remains the same. Therefore, the second experiment has more diversity in the men class than the third one.

Averaged results of the 10 times 10-fold cross validations are shown in Table 2. When focusing on classification accuracy, although the three results are very similar, the baseline approach achieved better results than the two other methods. However, this higher ac-

curacy hides a strong imbalance between the recognition rates of the two classes, which are 78.4% and 98% for the women (TPr) and men (TNr) classes, respectively. In the case of the two imbalance-sensitive methods, the difference between both rates is much more moderate due to a significant improvement in the TPr, and a slight degradation of the TNr.

A joint view of these two rates is given by the Gmean and AUC metrics, which compute unbiased measures of the classifier performance. As regards these metrics, the approach based on balanced classes at person level produces results that are quite a lot better than those of the baseline experiment. When the two imbalance-sensitive methods are compared, the one which balances at person level seems to be able to better generalize because of the greater number of sequences for each man represented.

A direct comparison between these results and those from previous related works is not appropriate because all of them are defined in terms of different feature extraction strategies, classification models, error evaluation schemes and training and test partitions. Nevertheless, their main gender recognition results on the CASIA Gait Database are shown here to allow for a broader analysis of results. These works presented their classifier performance only in terms of accuracy, and these results are very close to those introduced in this paper: 85% from (Lee and Grimson, 2002), 89,5% from (Huang and Wang, 2007) and 95.97% from (Yu et al., 2009). However, as was demonstrated above, accuracy is not a reliable measure in imbalanced scenarios.

5 CONCLUSIONS

An exhaustive study designed to evaluate the capacity of the CASIA Gait Database for gender recognition tasks was carried out. This dataset contains gait samples from 124 subjects, distributed in an unbalanced way with 31 women and 93 men. To our knowledge, the papers that have previously worked on this collection have avoided dealing with its imbalanced nature by using reduced balanced subsets. Therefore, there seems to be no previous results considering the whole dataset for benchmark purposes.

This paper proposes a methodology to learn from the CASIA Gait Database while dealing with its imbalanced complexity, and to suitably evaluate the effectiveness of the resulting classifier. In particular, a distributed learning approach within a classifier ensemble, and some metrics to appropriately measure the classification performance in an imbalanced context, like AUC and the geometric mean of per-class

Table 2: Experimental results.

Measure/Experiment	Baseline	Balancing At Sequence Level	Balancing At Person Level
Accuracy	93.1% \pm 0.77%	92.1% \pm 0.61%	91.8% \pm 0.56%
TPr	78.4% \pm 1.92%	84.5% \pm 1.2%	87% \pm 1.55%
TNr	98% \pm 0.59%	94.6% \pm 0.53%	93.4% \pm 0.5%
Gmean	87.6% \pm 1.17%	89.4% \pm 0.79%	90.1% \pm 0.86%
AUC	88.2% \pm 1.07%	89.6% \pm 0.77%	90.2% \pm 0.84%

success rates were considered.

The imbalance-sensitive approach was compared with a plain method based on a single classifier. When the global classification accuracy was used, the results of both strategies were very similar but, when AUC and Gmean were considered, the proposed strategy was significantly better. This result can be explained by scrutinizing the recognition rates per class since the proposed approach improved this rate quite a lot for the women/minority class, while the rate for the men/majority class was only slightly reduced.

Regarding the use of the whole CASIA Gait Database through its own silhouette frames and the application of standard methods of learning and error estimation, the strategy proposed here could become a good benchmark for future comparisons of gait-based gender recognition. This preliminary work could be improved by using that strategy on more databases, with other classifiers and taking into account other feature extraction methods.

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