# THE ROLE OF ONLINE AND OFFLINE FEATURES IN THE DEVELOPMENT OF A HANDWRITTEN SIGNATURE VERIFICATION SYSTEM

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## Abstract

In this paper we investigate the importance of online and offline features for development of handwritten signature verification systems. We also discuss the difference between online and offline features, and compare the pros and cons of verification systems that use only online features to those that use only offline features. We then show that the best way to compare signatures is by using a combination of both online and offline features. Experimental results are reported for comparison of feature performances.

## INTRODUCTION

With the advent of high security applications in the computer industry, the need for security softwares has received much importance. Passwords and encryptions are pretty complex. No matter how complex they may be, they are not impossible to crack. This gave rise to methods for secure computer access, based on biometric techniques. Biometric techniques are secure techniques that can be used anywhere where access controls, financial security, contractual matters are involved. Biometric techniques are those techniques where human characteristics, and his/her unique properties are used. Examples of these are, eye or retinal scanning, fingerprint identification, voice recognition and other such techniques. There are some techniques where biometrics are coupled with the older conventional methods, like passwords etc, where apart from checking the correctness of the password, the way the user has typed it is also checked. All these biometric methods are either too expensive to implement or they are all still just ideas on the table which do not have good implementations yet, and therefore cannot be put to serious use, or both. All except two – Fingerprint identification and Handwritten signature verification. Handwritten signature verification systems are as effective as any of the other biometric techniques, because they exploit the uniqueness of the way the human being does something just as well as any of the other systems. The method of handwritten signature verification being comparatively much easier to implement when compared to the other biometric techniques, is much cheaper than them. The equipment necessary for this method is also quite cheap. All one needs is a stylus to be able to accept the signature.

No matter how hard a forger may try, he/she won't be able to get both the statics and dynamics of a signature correct. The harder he/she may try to get the looks right, the dynamics waver from the original that much more, and vice versa.

Every person's signature has unique features. Each feature may not be absolutely unique, but a combination of the various features can clearly distinguish the signature. A few examples of features may be the number of pen-ups (the number of times the

pen is lifted off the paper); the number of backtracks along the X and Y direction. The total area covered by the signature, etc.
To process a signature one needs to extract these features and exploit the difference in the combination of the features of the signature.
Any signature verification system will have to *learn* a few signatures before being able to decide if they are similar to others or different from them.
In order to be able to classify signatures, a template or reference set is formed out of the feature statistics of the training set of signatures. This template or reference set is what is going to be used to validate further test signatures. The template or feature set is therefore the most important thing required for handwritten signature verification, and being able to come up with an optimal template or reference set is therefore all the more important, since not all combinations of the features of signatures are going to be absolutely unique.
The feature set can be broken up into global features and local features. Global features are those that are extracted from the signature as a whole, while local features are based on parts of the signature and not the whole signature. The local features are more sensitive than global features to handwriting variations. Features can also be classified into online features and offline features. Online features are based on the dynamics of the signature and on the features that are extracted while the user is signing, while offline features are based more on the looks of the signature and the static components of the signature. Examples of offline features are total length of the signature, area covered by the signature etc. and online features can be the total time taken to write the signature, the ratio of the fastest written part to the slowest written part, etc. The definition of these features and the best combination of them to classify are discussed in the rest of this paper. We have emphasised the importance of online features in this paper. There have been enough studies on the importance of offline features for character and signature recognition.

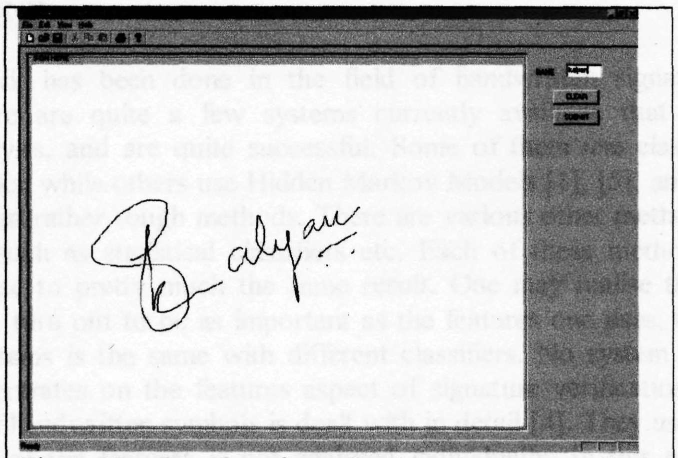

Fig 1: User interface for collecting signatures online

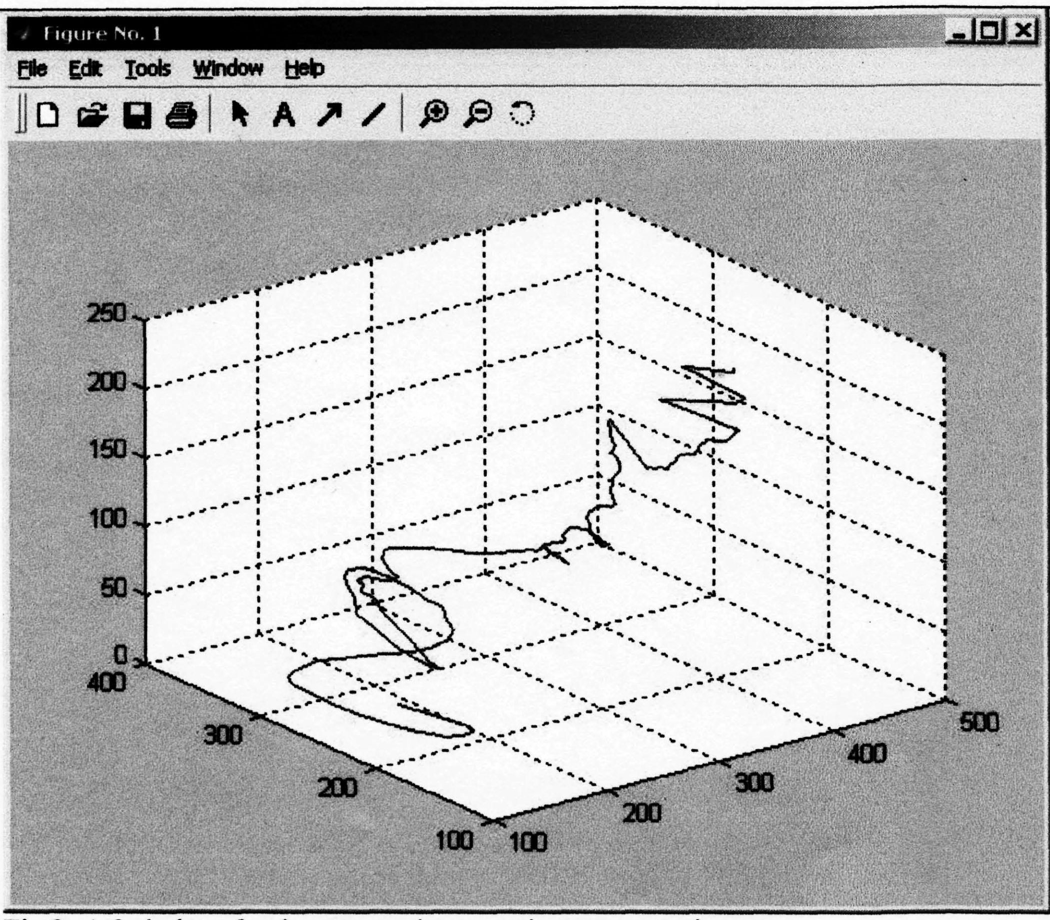

Fig 2: A 3-d plot of a signature, where z-axis represents time

## BACKGROUND

Extensive work has been done in the field of handwritten signature verification systems. There are quite a few systems currently available that do handwritten signature analysis, and are quite successful. Some of them use classifiers based on neural networks, while others use Hidden Markov Models [1], [5], and others use less complicated but rather rough methods. There are various other methods too that one can employ, such as statistical classifiers etc. Each of these methods if well done would give rise to pretty much the same result. One may realise that the classifier used does not turn out to be as important as the features one uses, because the final result one obtains is the same with different classifiers. No system so far however, actually concentrates on the features aspect of signature verification, though online recognition of handwritten symbols is dealt with in detail [4]. They use a few features, but each one of the features is not analysed individually. In this paper, more than concentrating on the system, we emphasise the necessity and importance of features. Each feature is described in detail and we consider the circumstances under which each feature can be used for best results. We also identify features that are among those that must be included in a system, and those that a system can do without.

Current online signature verification systems use a majority of online features alone, and concentrate on stroke [3], and the dynamics of the signature [6]. Some systems use a few offline features [2], and offline systems do not use any online information. The best combination could however be a combination of both offline and online features, wherein we take the best of both worlds. This way we could get better results

when compared to using only offline or only online features, and studying this combination would help us all the more.
An online signature is collected on a stylus, as a series of points (which need not be neighbouring), as shown in Fig 1. The time plays a significant role in this (Fig 2). An offline signature could be a binary image where black pixels represent part of the signature, and white pixels could represent empty space.

## FEATURES

Every signature can be classified based on its unique features. Every feature is given a value, and the combination of values of these features is what characterises the signature.
The different features that have been extracted are the following:

1. The total length of the signature:
   This feature is to calculate the total length of the signature from the start of the signature to the end.
   **Method:** The way to extract this feature is to calculate the distance between two neighbouring points (need not be very close), and to do so between all the pixels from the first one to the last one. This is an offline feature, because it's possible to calculate this length both on a scanned image and on a signature that has been accepted on a stylus.

   $$\sum\sqrt{(x_i-x_{i-1})^2 + (y_i-y_{i-1})^2}$$

   **Properties:** This feature does not depend on the position where it is written or on its orientation. However it is not independent of scaling, and therefore the distance when calculated, after scaling down to proportion, would always be a more consistent feature.

2. Sum of all the points from the origin:
   This feature calculates the sum of the distances of all the points from the start of the signature. This feature would be heavily dependent on the time taken to write the signature. Assuming that the time taken is close to a constant we could get a very accurate set of features per person.
   **Method:** Calculate the distance of every point from the start of the signature, and sum it up to obtain the value of this feature.

   $$\sum\sqrt{(x_i-x_1)^2 + (y_i-y_1)^2}$$

   **Properties:** This feature is independent of the position, and orientation, but is dependent on the size of the signature. Therefore the only operation to do while pre-processing it would be to scale it down to a constant size.

3. Average distance of the pixels from the start:
   When a user signs on a stylus, all points of contact are not taken into consideration. There is a particular sampling rate at which the point samples of the signature are obtained. So as the speed with which the signature is written increases, the distance between two consecutive pixels increases. This feature records the average distance of a point from the start of the signature. This is

an online feature because it can only be computed for signatures that are written on a stylus and tracked while doing so.
**Method:** Calculating the sum of distances of every point from the start of the signature, and counting the number of samples in the signature can extract this feature. Now on dividing the sum by the number of samples, one can obtain the average distance of every point from the start.

$$\sum\sqrt{(x_i-x_1)^2 + (y_i-y_1)^2} /N$$

**Properties:** This feature does not depend on the position where it is written or its orientation. Size of the signature however does make a big difference. When compared with the sum this turns out to be a much better feature, because if the time taken to write the signature were longer, then the sum would increase drastically, but since the number of samples also increases, the average would remain a constant.

4. Max distance between two points:
Similar to the average distance between two pixels, one can also find the maximum distance between two consecutive pixels. The faster a user writes, the larger this value is likely to be. This is also an online feature.
**Method:** One should go from the starting point of the signature to the end, and find the maximum distance between any two consecutive points in this way.

$$\text{MAX of} \sqrt{(x_i-x_{i-1})^2 + (y_i-y_{i-1})^2}$$

**Properties:** Like the above two features, this too is independent of translation and rotation, but scaling and speed at which the signature is written could change the value of the features.

5. Area cover by the rectangle covering the signature:
When the user signs, a close fitting rectangle can be placed on the signature. The area of this rectangle would be the value of this feature. This is an offline feature.
**Method:** One finds the minimum and maximum value of X and Y, and the difference between the maximum and minimum in both these directions, would give one the length and the breadth. The area can be computed by multiplying the two.
**Properties:** The area covered by the close fitting rectangle does not actually depend on the position it is written at or its orientation, but one must take into consideration translation, rotation and scaling in order to obtain consistent values all the time.

6. Ratio of length to breadth of the signature:
Similar to the above feature, the length and breadth of the signature can be computed, and the ratio between the two can be found out.
This is an offline feature.
**Method:** Just like the area, one must compute the length and breadth of the signature, and divide the length by the breadth to get the ratio.
**Properties:** Like the above feature, the ratio of length to breadth is as such independent of its position and orientation. Thus one must take care to make

sure that the rectangle fitting the signature is the closest fit, or a fit that is always constant. Thus this feature is translation, rotation and scaling independent.

7. Ratio of the area covered by the signature to the area covered by the rectangle:
Since we know the area of the signature and we also know the total length of the signature, we could compute the ratio of the two.
This is also an offline feature.
**Method:** After obtaining the area of the close fitting rectangle, we could divide the length of the signature by this to obtain the ratio.
**Properties:** An earlier described feature (area of the close fitting rectangle) cannot always be considered constant. When a person signs a little larger than usual the area increases a lot. In order to keep that feature constant, one must either sign with a constant sign all the time (which is not quite feasible), or we should divide the area by another equally variable feature. So the ratio of the area of the close fitting rectangle to the area covered by the signature would be a more appropriate ratio.

8. Angle that the start of the signature makes to the X-axis:
After a signature has been written one can compute the angle between the start of the signature and the X-axis.
This is an offline feature.
**Method:** The angle that the line joining the first two pixels makes with the X-axis is the value of this feature. It can be computed by finding the difference in Y coordinates and X coordinates of the two points. After that we can find the difference of these values in the two directions. On dividing the difference along Y with the difference along X, we can obtain the tangent of the angle. Finding the inverse tangent of this value we can find the value of the angle.
**Properties:** Being an offline feature, the signature has to be rotated so that each individual's signature is always oriented with a constant angle to the axes. When this happens, the angle that the start of the signature makes to the X-axis is always pretty constant. This feature being only based on the angle is independent of translations and scaling. However the signature is very heavily dependant on the orientation to the axes.

9. Angle that the end of the signature makes to the X-axis:
After a signature has been written one can compute the angle between the end of the signature and the X-axis.
This is an offline feature.
**Method:** The method is similar to what was done above, but only instead of considering the first two points, one must consider the last two points.
**Properties:** Similar to the above feature, the signature is independent of position and size, but is very sensitive to orientation. When compared to the angle at the beginning of the signature, this is not that efficient a property, because most people tend to start their signatures off in a standard manner, but different signatures of the same person do not always end similarly.

10. Number of backtracks of the signature along the X-axis:
No signature always proceeds in one direction; there are lots of fluctuations in the direction of writing. The user may start signing moving in the positive X

direction, but before he/she ends his/her signature, there might be a number of strokes going back and forth in the X direction. This can be considered to be an online feature.
**Method:** While signing, we have to check to see where the current points X value is less than that of the previous point. This denotes that the signature is now proceeding in the negative X direction. Similarly one can also find where its going in the positive X direction. The points where the direction changes can be considered to be a back track.
**Properties:** Since the signature is based on the X-axis, it is dependant on orientation, but since its only the backtracks that are going to be counted, the size of the signature and its position do not affect the feature in anyway.

11. Number of backtracks of the signature along Y-axis:
Similar to above if we apply the same logic along the Y direction, we shall obtain the number of backtracks alo.ıg the Y direction. This also can be considered to be an online feature.
Just like that above feature, the feature is heavily dependant on orientation, but is independent of the position and size, and is therefore scale and translation invariant.

12. Number of backtracks from the origin of the signature:
The above two features extract the number of backtracks along the two directions. However if its necessary that the signature be independent of the X and Y-axes, then the number of backtracks can be found with relation to the origin of the signature.
This can also be considered to be an offline feature.
**Method:** We calculate the distance of the current point from the origin, and when the previous distance so computed is more than the current distance, then it means that the signature is going backward toward the origin of the signature. When the current distance is more than the previous distance, then the direction is away from the origin, and the number of direction changes this way can be computed and set as the number of backtracks.
The same logic can also be applied to the end of the signature to get the distance from the end.
**Properties:** Since the previous two features were dependant on the orientation, we would like to have this feature independent of orientation too, and therefore we can check the signature without any pre-processing. This can be done by finding the number of backtracks from and to the starting point of the signature. This also is a more effective feature, because we are actually keeping track of the path that the person is following while signing, and while trying to forge it one can never get this feature right.

13. Total pen-down time:
Different people take different amounts of time to sign. So one can compute the total time taken by a person to write a signature. This is an online feature.
**Method:** Since the points in a signature are sampled at constant intervals of time, the total number of samples in a signature could be considered to be a constant factor of the time taken to write the signature. Therefore by counting the total sampled points in a signature one can obtain the time taken to write it.

**Properties:** Since this is a simple feature, that just counts the number of samples so far, its independent of position and orientation. If considered individually it is also independent of size, however we can't quite consider that this is the case because as the size of the signature grows, the time taken to write it will also change.

14. Total number of pen-ups:

Different people may lift the pen up a different number of times while signing. Therefore the number of such pen-ups can also be used as a feature.

This is an online feature.

**Method:** While reading the signature, keep a count of the number of times the user lifts the pen.

**Properties:** This is one of the simplest features. Its nothing but counting the number of discontinuities in the signature while the person is writing, and is therefore independent of size, orientation, position, and time taken to write the signature.

15. Connected component ratios:

Based on the number of pen-ups that a person might have in his/her signature, one can break the signature into parts that are connected. Each connected part will have its own distinct features. Now a person may take different amounts of time to write each separate component. We can take the ratio of the time taken to write a component to the time taken to write the whole signature. This would give the value for this feature. This feature is an online feature, but can also be considered to be a local feature, because it's based on each separate component as such.

**Method:** Find the number of samples in each component of the signature. Divide each one of these with the total number of samples in the whole signature to get the ratio.

**Properties:** This feature is a local feature, and is dependant on each connected component of the signature and the time taken to write it. Since this feature is independent of all other properties except for time, the position, orientation, and size does not matter at all. In fact the time taken also does not matter. This is because the speed taken to write separate components of the signature may be different, but if the relative speed is pretty much constant throughout, then the ratios will always be similar.

16. Connected component ratio products:

After one finds out the ratio of each connected component, we can find the product of the different ratios. This is an online feature.

**Method:** We just have to multiply the value of the ratio of each connected component.

**Properties:** There are many people who have equal number of connected components in their signature, but each component need not take exactly the same ratio to the whole signature. So in case, one wants to use the connected components feature without actually collecting all the component ratios, a product of all the ratios can be used which will also be unique even for small variations in the connected component time ratios.

17. Ratio of total positive displacement to total negative displacement along X:

For various signatures the length and total length may be equal, which is where this feature comes of use. One must find the total displacement in the positive X direction and total displacement in the negative X direction. After finding these, one can find the ratio of the two. This is an offline feature.
**Method:** In the signature we have to find the sum of all the traversals along the positive X direction and all the traversals along the negative X direction, by using the concept explained in backtracks above. After finding this, the ratio of the positive and negative displacements can be found.
**Properties:** There are times when the total length of a signature of more than one person may be equal, in which case the total displacement along X in the positive direction, and the total displacement along X in the negative direction hold a constant ratio for a single persons signature.

18. Ratio of total positive displacement to total negative displacement along Y:
Similar to what was done above, one can also use the same logic along the Y direction, to get the ratios for Y.
Similar to above, the same thing can be done in the Y direction. However in both cases the feature is dependant on the orientation to the axes, but is independent of the size and the position.

19. Standard deviation along X:
As the title says, for this feature we find the standard deviation of the sample points along the X direction. This is an online feature.
**Method:** We find the mean of all the X values of the sample points, and for every point we calculate the difference between the current value of X and the mean of X, and square it. We sum all the values from the initial to the final point, and divide it by the number of points, and then find the square root.
**Properties:** Since the value is based on the x coordinates, it is based on the location and orientation, and the size. Therefore this is one feature that one might consider using when one has a normalising function that takes care of all three aspects, i.e. rotation, translation and scaling.

20. Standard deviation along Y:
Similar to what was done above, we can also do the same along the Y direction.
This feature is similar to above; only it's in the Y direction instead of the X direction.

21. First derivation maximum value:
As stated the first derivation is the difference between the current position and the previous position. So we get the distance between the two points. We find the maximum such distance, and multiply it with the sample point it occurs at. This ratio always remains constant. This is an online feature.

22. First derivation average value:
As above, we find the total of the first derivations, and divide it by the number of samples, therefore getting the average value. This also is an online feature.

23. Maximum acceleration bell ratio:

People normally tend to sign at a standard speed all the time, but there are instances when the time taken to write the signature is more than normal. Under such circumstances, the basic ratios of the time at which parts of the signature are written remain the same. So one can find the point where the increase in speed of writing increases, till it peaks, and then starts to do down till it starts rising again. One can find the maximum such peak, and take that as a feature, when multiplied by the point where it occurs in relation to the peak. This is an online feature.
**Method:** Find the point where the increase in speed starts, till it keeps increasing. Then note the peak when the speed highest, then find the deceleration till it reaches zero or starts to increase again. Find the maximum such peak, and multiply it with the position where the peak occurs in that particular bell.
**Properties:** This feature is based on time, and therefore, one need not be particular about its position, and orientation, and size at all. All that one has to bother about is the time.

24. Maximum acceleration bell occurrence position:
When the maximum peak of the bell is found, the bell need not necessarily be symmetric in shape. When this is so, the position of the peak in relation to the size of the bell can also be considered a feature, because the peak will always occur at the same point in relation to that bell.
**Method:** Find the point of occurrence of the peak with respect to the bell, and divide this with the width of the bell, to get this ratio.
**Properties:** Like above this feature is also dependant only on time, and therefore one need not bother about position, or orientation, or size.

25. Minimum acceleration bell ratio:
Similar to the maximum bell, the minimum bell also can be computed.
It's also independent of the 3 physical corrections, being similar to the above two.

26. Minimum acceleration bell occurrence position:
The same way that the maximum bells position is found, even the minimum bells position can be found.
It's also independent of scaling, rotation, and translation, and has the same dependencies as the above features.

## EXPERIMENTAL FEATURE SELECTION AND DISCUSSION

There have been twenty-six features that have been discussed above, though in reality there can be many more features – about 90 features have been identified, which are both offline and online. However no handwritten signature verification system can incorporate all 90 features. Under different circumstances, a different number of features shall be required for signature verification. Consider a small handwritten signature verification system, where one or two features will have to do to be able to identify the signature. A system like this may be needed for a hardware implementation of a signature verification system. A classifier based on neural networks or hidden Markov models or any of the other statistical methods could be implemented, but there might not be enough resources to hold and implement more than a few features. Moreover addition of new features is not guaranteed to improve the results. Due to this we shall be analysing all the situations of any number of features, and the best combination of those many features among those that are present.

We have with us a small database that is continually being built which contains around four hundred signatures. The studies are carried on this data set. The presence of this small database could be a reason for considerably high success rates. Where we obtain a success rate of 100%, the actual success rate could drop to about 93-98% on an average for an extremely large database of signatures. A considerably good combination of features may give us a success rate of about 99%, and an extremely bad combination would give us something like 85-89%.

The signatures are being collected using an UC-LOGIC penkeyboard that has been interfaced with a computer with a Pentium-III processor, with 128 MB RAM. The classifier that has been used is based on a back propagation neural network algorithm.

The best feature need not necessarily be online. Even an offline feature would suffice if it were better than the online one. The following table shows the success rates of the best single features.

| Features being used | | Accuracy with that feature |
|---|---|---|
| Rank | Feature | Classification success rate |
| 1 | First derivation maximum ratio | 100% |
| 2 | Maximum bell ratio | 90.97% |
| 3 | Number of penups | 87.1% |

<u>Analysis</u>: We see that the first feature is an online feature, and thinking about it we notice that the first derivations maximum ratio value will certainly be very unique per person, as this finally translates to a feature totally dependant on the way the person writes with the pen. The second ranker is the maximum bell ratio, which for a single person shall always be constant, no matter what speed he/she may write his/her signature at. This also is quite unique for a person. The third ranked is the number of penups, which has turned up at this position because the number of people in the database is not too many, and each one virtually has a unique number of penups in his/her signature. This however will not be too helpful if the number of people in the database increases.

The accuracy results with 2 features would certainly be far better than just with one, so we shall analyse these results now. The table below shows the best combination of two features, and its success rates.

| Features being used | | | Accuracy with that feature |
|---|---|---|---|
| Rank | Feature 1 | Feature 2 | Classification success rate |
| 1 | Max bell ratio | No. Of backtracks | 100% |
| 2 | Max bell ratio | Signature area to rectangle area ratio | 100% |
| 3 | Max bell ratio | Positive negative displacement ratio along X | 100% |

| | | | | |
|---|---|---|---|---|
| 4 | Min bell ratio | First derivation maximum ratio | | 100% |
| 5 | Angle that the start makes to the X-axis | Positive negative displacement ratio along X | | 100% |

Analysis: We now notice that all the above feature combinations have an accuracy of 100%. This is because, each one of then identifies a unique feature, and that feature alone can pretty closely identify the signature. When this is combined with another such feature, where the two features that combine have no correlation to one another, then they are absolutely independent in identifying the class the signature belongs to. This way the combination of the two identifies a very unique feature in the signature that can identify the class.

We notice that the first three cases contain the maximum bell ratio, with another totally independent feature. The first one among them is the number of backtracks with respect to the start of the signature, which is an offline feature which is independent of translation, rotation, and scaling. The second such feature that is used is the ratio of the area covered by the signature to the area covered by its close fitting rectangle. The third case uses the ratio of the positive displacement to the negative displacement along the X-axis. In the fourth case we combine the minimum bell ratio with the first derivation maximum ratio that identifies the signature perfectly because each one of them is unique in its own way but both features are independent of one another. The last of the combinations uses the angle that the start of the signature makes to the X-axis, and ratio that the positive displacement makes to the negative displacement along the X direction, where both are offline features. Hence we see that it's not absolutely necessary to have only online features.

We consider the combination of three features here.

| Features being used | | | | Accuracy with that feature |
|---|---|---|---|---|
| Rank | Feature 1 | Feature 2 | Feature 3 | Classification success rate |
| 1 | Max bell ratio | No. Of backtracks to the start of the signature | Nearly all other features | 100% |
| 2 | Max bell ratio | Nearly all other features | First derivation maximum value | 100% |
| 3 | Max bell ratio | Total sum of distances of all points from the start of the signature | Nearly all other features | 100% |
| 4 | Max bell ratio | Maximum distance of a point from the start of the signature | Signature area to rectangle area ratio | 100% |

| | | | | |
|---|---|---|---|---|
| 5 | Angle that the start makes to the X-axis | Signature area to rectangle area ratio | Nearly all other features | 100% |
| 6 | Max bell peak position | Nearly all other features | Connected component ratio product | 100% |
| 7 | Max bell peak position | Nearly all other features | Signature area to rectangle area ratio | 100% |
| 7 | Max bell peak position | Nearly all other features | Ratio of positive to negative displacement along X | 100% |

Analysis: In the above table there is more than one instance where one of the features is 'Nearly all other features', this applies for all other features except those that are correlated to one of the two given features. Even in the case of three features being used we notice that we obtain 100% accuracy with a combination of three features, where each feature is somewhat successful individually and all three features are not correlated in any way whatsoever.

We have kept the local feature (connected component ratio out of all the tables above, because its success rate is rather high, and every combination with that feature in it was a success. In cases where this alone was used, it gave a 100% accuracy rate for anyone who had more than one connected component in their signature, however signatures with only one connected component in it always had a ratio value of 1 and therefore was not successful. So any system that can incorporate that feature, and any other efficient feature would certainly be successful.
After the above few sections of analysis we notice that a set of features used can be quite successful if each of the features identifies a unique property of a person's signature successfully, and each one of the features so chosen should be independent of one another, and each feature should also be able to classify the signature close to the accurate value.

## FUTURE WORK

This paper has so far only been discussing a conceptual and preliminary experimental study. Online features have been discussed more, and it needs more shape based offline features to be incorporated.
A classifier based on Hidden Markov Models will be incorporated. System dependent issues also shall be considered, wherein driver dependent issues shall considered, efficiency issues will also be considered. We will also be trying to implement it in different platforms, and Operating Systems.
The final version of this paper will contain more experimental studies on feature selection.

## CONCLUSION

All the different features that have been collected so far have been studied individually, and an optimal solution has been reached for checking handwritten signatures. The pros and cons of each feature have also been explained to a substantial extent. We finally notice that with this we could design a system that can be nearly perfect with a mere 5-6 features. So thinking about all the 90 possible features would be absolutely unnecessary.
The final version of this paper will contain more experimental studies on feature selection.

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