A Hybrid Statistical IHS Image Fusion Method

Ali Reza Afary1, Mohammad Javad Valdan Zoj2, Hassan Emami3
1Ali Reza Afary, Babol University of Technology, Babol, Iran (E-mail: afary@nit.ac.ir)
2Mohammad Javad Valdan Zoj, K.N. Toosi University of Technology, Tehran, Iran
(E-mail: valadanzouj@kntu.ac.ir)
3Hassan Emami, University of Tabriz, Tabriz, Iran (E-mail: h_emami@tabrizu.ac.ir)

Abstract:
IHS method for image fusion is one of the conventional methods with a simple theory. Implementation of this method is simple and effective from computational point of view. But this method causes the spectral content of the fused image to get disturbed in comparison with the spectral criteria of the main multispectral image. In this article a statistical image fusion method is combined with the conventional IHS method to improve its spectral quality and overcome its deficiency. Some spectral indices were used for evaluation of this combined method and compared with the conventional IHS and the used statistical fusion methods. This combined method improves the spectral quality of the fused image and eliminates the existing shortcomings of the spectral disturbing in fused image produced by IHS method.

Keywords: Image fusion, IHS, Statistical method, Spectral quality.

1. Introduction
Remote sensing satellites take images at different spatial, spectral and temporal resolutions from earth surface in different parts of the electromagnetic spectrum. The aim of satellite image fusion is to unite their spatial, spectral and temporal information, and also to increase their reliability in order to increase interpretability. In the act of fusing multispectral satellite images (XS), having high spectral and low spatial resolutions, with a panchromatic image (PAN), having high spatial resolution, the final production must be the same as the image took simultaneously by a sensor with the same spectral resolution of XS image and spatial resolution of PAN image [1,2]. Image geo-referencing or image to image registration, and resampling of XS image into the spatial pixel dimensions of PAN image, is one of the primary and main parts of the image fusion process [3]. If the images used in the fusion process have not been taken simultaneously, it will be necessary to apply a series of radiometric corrections such as the histogram matching of PAN image histogram with the histogram of the Intensity element of XS image. Image fusion may be done in three levels of pixel, object and decision making [3]. This article is on the pixel level image fusion.

1.1 The Studied Region and Data
Three data sets were used in this article; QuickBird (PAN and XS), Worldview-02 (PAN and XS), and EO1-ALI (PAN band) with Landsat TM(Fig.s 1-6). Because of the limitation of custom IHS method in accepting only three bands of XS image [3], just three bands from multispectral images were selected and used in fusion process. TABLE I is showing the criteria of all data sets that are used in this article. Dimensions of the studied PAN and XS images (after resampling XS image to corresponding PAN image pixel size) are 1024×1024 pixels.

1.2 IHS Image Fusion Method
This method is a spectral substituting method in pixel level which is done by transforming of XS image from the RGB color space to IHS color space and substituting its spatial element, Intensity, with PAN image and then doing the reverse IHS transform and coming back to the RGB color space [3-6].

29
1.3 IHS Color Space

In image processing, IHS colored space is used as a means for separating spatial element, Intensity, from spectral elements, Hue and Saturation, of a three banded image. There are different methods to accomplish this separation [3-10]. In this research transforming from RGB color space to IHS and vice versa is done through Equations (1) and (2) [9]. From among different methods of computing Intensity element in IHS transformation, using Equation (1) will end in better results [10], which is also used in this research. The fused images using IHS method have been shown in Fig.s 7-9.

\[
\begin{align*}
[I] = \begin{bmatrix}
\frac{2}{3} & \frac{1}{3} & \frac{1}{3} \\
-\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} \\
\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} & 0
\end{bmatrix},
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = \begin{bmatrix}
\sin(H) \\
\cos(H)
\end{bmatrix}
\end{align*}
\]

\[
\begin{align*}
R &= \frac{\sqrt{6}}{2} - \frac{\sqrt{6}}{6}v_1 + \frac{\sqrt{6}}{6}v_2 \\
G &= -\sqrt{6}v_1 - \sqrt{6}v_2 \\
B &= \sqrt{6}v_2
\end{align*}
\]

Table I: Criteria of Data Sets Used in this Article

<table>
<thead>
<tr>
<th>Sensor</th>
<th>QuikBird (PAN &amp; XS)</th>
<th>Worldview-02 (PAN &amp; XS)</th>
<th>EO1-ALI (PAN) and Landsat TM5 (XS)</th>
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<tbody>
<tr>
<td>PA</td>
<td>R = B4, G = B3, B = B2</td>
<td>PA, R = B7, G = B5, B = B3</td>
<td>PA, R = B4, G = B3, B = B2</td>
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<td>0.50-0.90, 0.76-0.90, 0.63-0.69, 0.52-0.60</td>
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<td>0.48-0.69, 0.76-0.90, 0.63-0.69, 0.52-0.60</td>
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<tr>
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<td>0.5</td>
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<td>2010-05-30</td>
</tr>
<tr>
<td>Bits Per Pixel</td>
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<td>8</td>
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</tr>
<tr>
<td>Coordinate System</td>
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<td>UTM Z39N (WGS84)</td>
<td>UTM Z38N (WGS84)</td>
</tr>
<tr>
<td>Location</td>
<td>Marvdasht near Shiraz city of Iran</td>
<td>Tehran City, Capital of Iran</td>
<td>Urmia City of Iran</td>
</tr>
</tbody>
</table>

Fig 1: QuickBird XS image (B432)  
Fig 2: WorldView-02 XS image (B753)  
Fig 3: Landsat TM5 XS image (B432)
2. A REVIEW ON IHS FUSION METHOD

In the first IHS based image fusion procedure, proposed by Haydn et al in 1982 [11], the Intensity component of XS image was directly replaced with the PAN image. It is known that although this method provides fused images with enhanced spatial quality, their spectral information differs significantly from that of the original multispectral ones. Image fusion with IHS method has some disadvantages and commonly distorts the spectral quality of the fused image in comparison with the main multispectral image, especially in Green and Near Infra-Red (NIR) bands [4,5,12]. Besides, this fusion method when applied on images with different resolutions, lead to different results [13]. Different approaches have been proposed during the last decades to minimize the spectral distortion inherent to IHS fusion method. To decrease the spectral distortion, some methods such as histogram matching of PAN image with Intensity element of XS image are used [14]. Also stretching of Hue and Saturation elements before reverse transformation is suggested [14]. On the other hand the quality of the fused image in IHS method relates also to the sensor bandwidth of PAN image. In these methods, the best result is obtained when sensor band width of PAN image covers the whole sensor bandwidth of XS image like PAN sensor of Ikonos, QuickBird and WorldView-2 images [4,15,16]. To overcome these problems some authors [10,17] proposed to combine IHS method with multiresolution wavelet fusion method and inject, into the Intensity image, the spatial information of the PAN image, missing into the multispectral one, in a multiresolution wavelet frame. The wavelet coefficients of the PAN image, which pick up the spatial information of this one, are extracted using wavelet algorithm. This method is capable of enhancing the spatial quality of the multispectral image while preserving its spectral information. The wavelet method does not modify the total radiance of the XS image since the mean value of each of the wavelet coefficients is zero [10]. Taking into account the computational cost of the wavelet fusion method, as well as the methods proposed by Chibani and Houacine [18], Choi [19] proposed an alternative IHS based simplified procedure. In this case, the new Intensity image is obtained as a combination of the Intensity and PAN images and the tradeoff between the spatial and spectral resolution of the images to be fused can be controlled using a tradeoff parameter (\(t\)) [19].

Another shortcoming of IHS method is its limitation in using just three bands of XS image in the fusion process, accordingly the suitable bands must be chosen from among different bands of XS image [20]. For example, in Landsat ETM+ (7 bands), WorldView-02 (8 bands) and QuickBird (4 bands) images, just three bands of XS image must be selected for fusing with IHS method. In order to extend the IHS based image fusion methods, from three to n-bands, Tu et al. [4,5] proposed a new Generalized IHS fusion method.

3. STATISTICAL IMAGE FUSION METHOD

The Statistical image fusion Method - represented by ST symbol as follows - which is combined in this research with the IHS method
to improve its spectral quality is based on the method presented by Gungor and Shan [21]. This approach constructs the fused images as a linear combination of the PAN and XS images through Equation (3) in which \( i \) and \( j \) are the row and column numbers of each pixel and \( k \) is the band number of the XS and fused image \( F \), and \( N \) is the total number of the bands in the XS image.

\[
F_{ij}^k = a_{ij}^k \times \text{PAN}_{ij} + b_{ij}^k \times \text{XS}_{ij}^k \quad ; \quad k = 1, 2, ..., N
\]

Any pixel in the \( k \)th band of fused image is obtained by multiplying the corresponding pixels of PAN and XS images respectively by \( a \) and \( b \), the weighting coefficients, and calculating the sum of the products. For any pixel, the coefficients \( a \) and \( b \) must be determined window by window i.e. for calculating these coefficients in Equation (3), first two windows having \( w \times w \) dimensions is defined around any corresponding pixel in PAN image and in the \( k \)th band of XS image [21].

Padding process will be needed for the border regions of the input images. There are various padding approaches in the literature and in this study the zero padding approach which extends the images with zeros was used. On the basis of Digital Number (DN) values of pixels included in these windows and the statistical relations obtained from the two below criteria, the coefficients \( a \) and \( b \) are calculated [21]:

The first criteria: The mean of every fused image band should be equal the average of its corresponding XS image band.

\[
\mu_{F_{ij}^k} = a_{ij}^k \times \mu_{\text{PAN}_{ij}} + b_{ij}^k \times \mu_{\text{XS}_{ij}^k} = \mu_{\text{XS}_{ij}^k}
\]

(4)

Where \( \mu_{F_{ij}^k} \) is the mean of fused image in the \( k \)th band, is the mean of PAN image, and \( \mu_{\text{XS}_{ij}^k} \) is the mean of XS image in the \( k \)th band.

The second criteria: The variance of every band in a fused image should be equal with the variance of PAN image.

\[
\sigma_{F_{ij}^k}^2 = (a_{ij}^k)^2 \sigma_{\text{PAN}_{ij}}^2 + 2 \times a_{ij}^k \times b_{ij}^k \times \sigma_{\text{PAN}_{ij}, \text{XS}_{ij}^k} + (b_{ij}^k)^2 \sigma_{\text{XS}_{ij}^k}^2 = \sigma_{\text{PAN}_{ij}}^2
\]

(5)

Where \( \sigma_{F_{ij}^k}^2 \), is the variance of fused image \( F \) in the \( k \)th band, \( \sigma_{\text{PAN}_{ij}}^2 \), is the variance of PAN image, \( \sigma_{\text{XS}_{ij}^k}^2 \), is the variance of XS image in the \( k \)th band and \( \sigma_{\text{PAN}_{ij}, \text{XS}_{ij}^k} \), is the covariance of the \( k \)th band of XS image with PAN image. The above formulation applies for any pixel \((i,j)\) within the \( w \times w \) window defined around it. The larger the window, the more spatial contribution will be gained from the PAN image. This means that larger window size will produce spatially sharper fused images. However, larger window size will also result in degradation in the color. Therefore, there is a trade-off between spatial resolution gain and spectral content loss resulting from the window size. Hence, an optimal window size should be selected during the fusion process [21]. In this article for the possibility in comparison the results with the results that Gungor and Shan [21] have presented on their research, the window size was selected as 31×31.

Fig.s 10, 11, and 12 show the fused images with the ST fusion method with the 31×31 window size around of each pixel.

4. Combining IHS Fusion Method with ST Statistical Method

To improve the spectral quality of IHS fusion, we combined the IHS method with the ST method. In order to combine IHS method with ST method, XS image bands in Equation (3) are substituted with Intensity element, ‘I’, which is obtained from transforming RGB color space into IHS color space as in Equation (6). Accordingly, PAN image is fused just with Intensity element of XS image and produced the fused Intensity element of ‘I*’. By substituting this fused Intensity element ‘I*’ in the reverse IHS transform and creating a new I*HS group and then doing the reverse IHS transform and transferring it into the RGB color space, the fused image through this combined method is obtained. This method is shown by IHS-ST symbol as follows.

\[
I_{ij}^* = a_{ij} \times P_{ij} + b_{ij} \times I_{ij}
\]

(6)

Due to this combination, Equations (4) and (5) are rewritten in the form of Equations (7)
and (8), respectively.

\[ \mu_{I^*} = a_{ij} \times \mu_{P_{ij}} + b_{ij} \times \mu_{I_{ij}} \] (7)

Where \( \mu_{I^*} \) is the average of fused Intensity element ‘I*’, \( \mu_{P_{ij}} \) is PAN image average, and \( \mu_{I_{ij}} \) is the average of Intensity element of XS image.

\[ \sigma_I^2 = \left(a_y\right)^2 \sigma_{P_{ij}}^2 + 2 \times a_y \times b_y \times \sigma_{P_{ij}I_{ij}} + \left(b_y\right)^2 \sigma_{I_{ij}}^2 \] (8)

Where \( \sigma_I^2 \) is the variance of fused Intensity ‘I*’, \( \sigma_{P_{ij}}^2 \) is PAN image variance, \( \sigma_{I_{ij}}^2 \) is the variance of Intensity of XS image and \( \sigma_{P_{ij}I_{ij}} \) is the covariance of Intensity element of XS and PAN images. To calculate \( a_{ij}^k \) and \( b_{ij}^k \) coefficients, Equations (7) and (8) are used to obtain a second degree equation in terms of coefficient \( b_{ij} \) by substituting Equation (9).

According to Equation (7), it can be written as:

\[ a_y = \frac{\mu_{I_{ij}}}{\mu_{P_{ij}}} \times (1-b_y) = M \times (1-b_y) \quad \& \quad M = \frac{\mu_{I_{ij}}}{\mu_{P_{ij}}} \] (9)
By substituting $a_{ij}$ coefficient from Equation (9) into Equation (8), a second degree equation in terms of coefficient $b_{ij}$ is obtained.

\[
\left( M\sigma^2_{p_i} + \sigma^2_{t_i} - 2M\sigma_{p_i}t_i \right) b_{ij}^2 + \left( 2M\sigma_{p_i}t_i - 2M\sigma^2_{p_i} \right) b_{ij} + \left( M^2 - 1 \right) \sigma^2_{p_i} = 0 \]  

(10)

By solving Equation (10), two answers are obtained for $b_{ij}$ and as a consequence by substituting those into Equation (9), two answers are calculated for $a_{ij}$ coefficient. Noticing that the aim of combining PAN image and Intensity element of XS image is to transfer the spatial information of PAN image into Intensity element of XS image, so from among two obtained answers for $b_{ij}$ coefficient, the one which maximize the coefficient $a_{ij}$ and as a result, increases the effect of PAN image in the fused image is chosen to be used in fusion process. In some cases, $a_{ij}$ and $b_{ij}$ coefficients are complex numbers. Under such circumstance, the real components of the complex roots are taken as $a_{ij}$ and $b_{ij}$ coefficients, since they can make Equation (10) closest to zero in the domain of real roots [21].

Fig.s 13, 14, and 15 show the fused images by the combined IHS-ST method. Fig. 16 shows the flowchart of this combined method.

5. Spectral Quality Assessment of the Fused Images

As the aim of this article is the spectral improvement of the conventional IHS methods by hybrid IHS-ST fusion method, so in this study some statistical indices were used for spectral quality assessment of the fused images. The aim of studying spectral quality is to measure the degree of spectral similarity between a fused image and main XS image. For spectral quality assessment of the fused image, apart from visual study as a necessary step, a series of numeral and statistical indexes such as Inter-Band Correlation Coefficient Bias (IBCCB), Cross-Band Correlation Coefficient (CBCC), Root Mean Square Error (RMSE), Signal to Noise Ratio (SNR), Normalized Mean Absolute Error (NMAE), and Spectral Angle Mapper (SAM) were used in this study. Besides the IHS, ST and IHS-ST methods, for comparison, we are provided the fused images with three other common fusion methods: Principle Component Analysis (PCA) [3,4,22], Brovey Transform [3,4,22] and Additive Shift Invariant Wavelet Transform (ASIWT) fusion methods [23-27]. The fused images using PCA, Brovey and ASIWT fusion methods have been shown in Fig.s 17-25 respectively.

5.1 Visual Study of Fused Images

As a necessary step in quality assessment of fused images we visually explored the fused images by the IHS, ST and IHS-ST methods [2,28]. Visual inspection of the fused images shows that the visual quality of fused images by IHS-ST method did not disturb in fusion process and fused images by this method have similarity to the original XS image. Also no color spreading exists in the fused images by this method such as the color spreading exists.
in the fused images by the ST method.

5.2 Inter-Band Correlation Coefficient Bias (IBCCB)

Correlation coefficient (CC) between two variables A and B (in this case two image bands having dimensions MxN) is defined as Equation (11) and reflects the correlation complete non-homogeneity for value (-1) and also complete similarity between two images for value (+1).

\[
CC_{AB} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (A_{ij} - \overline{A})(B_{ij} - \overline{B})}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} (A_{ij} - \overline{A})^2 \sum_{i=1}^{M} \sum_{j=1}^{N} (B_{ij} - \overline{B})^2}}
\]

The IBCCB is calculated with Equation (12) as a spectral distortion index between the two bands of XS image (XS and XSj) and the corresponding bands in the fused image (Fi and Fj) [30]. The ideal condition is when the IBCCB value is
approaching to zero.

\[ IBCCB_{ij} = CC_{XSi} - CC_{F_{ij}} \]  

(12)

TABLE II shows the amount of IBCCB values between fused images’ bands and XS images’ bands. It is clear from TABLE II that combined IHS-ST method makes an improvement in the IBCCB index of the fused images in comparison with IHS and other methods especially between NIR Band and other two Red and Green bands.

5.3 Cross-Band Correlation Coefficient (CBCC)

Another index to measure the spectral quality of the fused image is the calculation of the correlation coefficient between fused image’s bands and its corresponding bands in XS image i.e. CBCC [28,30,31]. Much closer this value to (+1), there will be a more similarity between bands of fused image and XS image. To calculate this index, Equation (12) is also used with variable A from XS image and variable B from fused image. According to Zhang [28] this is the most reliable quantitative criterion in comparing the quality of two images. In TABLE III, it can be seen that the CBCC values of combined IHS-ST method is closer than IHS and ST methods’ values to (+1) especially in NIR band.

5.4 Root Mean Square Error (RMSE)

RMSE is a statistic of objective fidelity of fused image for assessing loss of the information in comparison with original XS image [32] and is calculated by Equation (13). This index measures the average amount of changes on any pixel caused by processing and are used to evaluate the similarity between the reference image XS and the fused image F [33]. The ideal value for this index is zero.

\[ RMSE_{jk}^2 = \frac{\sum_{i=1}^{N} \sum_{j=1}^{M} (XS_{ij} - F_{ij})^2}{N \times M} \]  

(13)

This index is a better criterion than CBCC and has more sensitivity [34]. Therefore if the quality of two different fusion methods regarding to Pearson’s correlation coefficient is the same, then the RMSE index can be used to determine the better method. As it is seen in TABLE IV, the RMSE of IHS-ST method compared to IHS and ST methods especially in NIR band are much less.

Signal to Noise Ratio (SNR) If fused image F, is considered to be the sum of the original XS image and a noise signal e, then the root mean square of Signal to Noise Ratio for fused image F, is denoted as SNRrms and is calculated by Equation (14):

\[ SNR_{rms}^k = \sqrt{\frac{\sum_{i=1}^{N} \sum_{j=1}^{M} (F_{ij})^2}{\sum_{i=1}^{N} \sum_{j=1}^{M} (XS_{ij} - F_{ij})^2}} \]  

(14)

This is a subjective fidelity criteria measuring image quality by subjective evaluation of a human observer [32] and is commonly used in assessing image fusion techniques [35]. The bigger is the value of SNRrms the better is the quality of the fused image. TABLE V shows the value of this index for the fused images. As it can be seen the SNRrms values for IHS-ST methods is better than IHS method and has especial improvement in NIR band.

5.5 Normalized Mean Absolute Error (NMAE)

The index NMAE measures the relative deviation of the fused image from the XS image and is calculated by Equation (15). A smaller NMAE implies the better spectral quality of the fused image [36]. As it is shown in TABLE VI, the NMAE value for IHS-ST method is much smaller than IHS method.

\[ NMAE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{|F_{ij} - XS_{ij}|}{XS_{ij}} \]  

(15)

Spectral Angle Mapper (SAM)

If each pixel values of XS image bands and its corresponding in the fused image are indicated with vectors V1(a,b,...,n) and V2(a’,b’,...,n’) in which (a, b ,...,n) and (a’, b’, ..., n’) are the gray values through band-1 to band-n, then the SAM denotes the value of the angle between these two vectors using Equation (16) [37].

\[ SAM = \arccos \left( \frac{V1 \cdot V2}{|V1||V2|} \right) \]  

(16)
In Equation (16) $\langle V_r^i V_r^j \rangle$ is stands for the inner product of the vectors and symbol $|V_r|$ is stands for the vector length.

For two similar bands of XS and fused image F, the SAM(XS, F) index is defined according to Equation (16) as the $E[\text{SAM}(a, b)]$, where $E$ denotes Expectation and $a$ and $b$ denotes the generic pixel vector element of multispectral image XS and F, respectively [37]. SAM is a global spectral distortion index and measures the average spectral distortion. The closer to zero the SAM value the more similar are images XS and F [37].

TABLE VII shows the SAM index values for different fusion methods discussed in this article. The combined IHS-ST method has better values than the IHS and especially ST methods.

6. CONCLUSION

According to the results shown in TABLEs II up to VII, the spectral quality of the images fused through IHS-ST hybrid method presented in this article is much better than the spectral quality of the images fused through conventional IHS method and also other methods, especially in NIR band. On the other hand the spectral quality of the IHS-ST method is better than the quality of ST statistical method and also the amount of computation is near to one third of ST method. Also the results of TABLEs II up to VII for EO1-ALI-PAN and Landsat TM5 data set, show this method has not any problem in the fusion of images from different sensors.

<table>
<thead>
<tr>
<th>table ii: Inter-Band Correlation Coefficient Bias Index (IBBCCB)</th>
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<tr>
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<td>------------------</td>
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<tr>
<td></td>
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<tr>
<td>IHS</td>
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<td>ST</td>
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<th>B2</th>
<th>B4</th>
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<th>B7</th>
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<td>ST</td>
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<td>4.0487</td>
<td>2.8627</td>
<td>8.4443</td>
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| Brovey | 2.2117 | 3.3292 | 2.8096 | 3.9091 | 4.1527 | 3.8528 | 5.4159 | 3.4995 | 1.4956 |

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<tr>
<td>B4</td>
<td>0.3447</td>
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<td>B3</td>
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<tr>
<td>B2</td>
<td>0.0767</td>
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</table>

| ST | 0.2429 | 1.0592 | 1.1241 | 0.1310 | 0.2329 | 0.3537 | 0.2740 | 0.3433 | 0.3820 |
| HHS-ST | 0.3451 | 0.1883 | 0.2110 | 0.1719 | 0.1719 | 0.2110 | 0.1662 | 0.2730 | 0.4789 |
| PCA | 1.5485 | 0.6400 | 0.7631 | 0.3024 | 0.0966 | 0.1289 | 0.2461 | 0.5558 | 0.1861 |

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<th>QB</th>
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</tbody>
</table>

7. REFERENCES


