A Novel Method for the Conversion of Scanned Electrocardiogram (ECG) Image to Digital Signal

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Abstract Electrocardiogram (ECG) is the record of origin and propagation of electrical potential through cardiac muscles. It provides information about heart functioning. Generally, ECG is printed on thermal paper. The person having heart abnormalities will have to maintain all the records for the diagnosis purpose, which requires large storage space and is minimized by storing in the computer using scanner. The stored data is processed manually, which is time consuming. So an automatic algorithm that is developed does the conversion of the ECG image to digital signal. In order to convert the image, image processing methods like binarization, morphological techniques have been used. Usage of morphological skeletonization helps in converting the image to digital signal form by finding the skeleton of the ECG signal. The performance of the conversion algorithm is analyzed using root-mean-square error (RMSE), and it was found good. The average error found between the binarized image and the skeletonized image is nearly 7.5%.

Keywords Electrocardiogram · Binarization · Morphology · Skeletonization RMSE

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1 Introduction

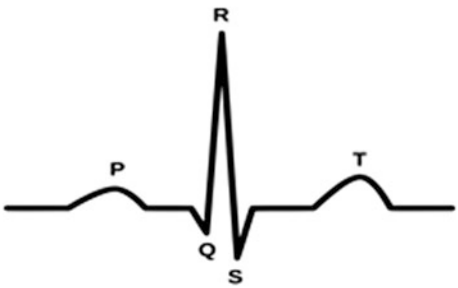
Heart-related diseases are one of the common causes of death. It kills millions of people worldwide each year. There are various kinds of heart-related problems. Arrhythmias are one of the problems related to heart. It occurs due to the abnormality in heart rhythm. They are accessible when the heart's electrical impulses run with the pack of heartbeats which do not function properly. Different types of arrhythmias include tachycardia, bradycardia, premature contraction and fibrillation. Generally, arrhythmia occurs when the electrical signal which controls the pulses is delayed or some time blocked. This can occur only if the nerve cells that deliver electrical signals won't work appropriately. Once the doctor has documented that the subject has an arrhythmia, subject will need to find out whether it is normal or abnormal or merely reflects the heart's normal processes [1].

Electrocardiogram (ECG) is the most important and generally used strategy to think about the heart diseases. The restorative condition of the heart is found by the state of the ECG waveform. This will help in separating the sorts of diseases. Over the previous decades, considerable work has been done to ease cardiologists' task of diagnosing the ECG recordings. The real test confronted today is the early identification and treatment of arrhythmias [2]. The representation of electrical activity of the heart is known as ECG. It demonstrates the standard contraction and relaxation of the heart muscle. The recorded data contains vital data about rhythmic attributes. It is the most effectively available bioelectrical signal that gives the sensibly precise information with respect to the state of the heart. The heart condition is analyzed by an equipment generally known as electrocardiography. The examination of ECG waveform will help in diagnosing the various abnormalities.

ECG comprises of five fundamental waves *P*, *Q*, *R*, *S*, and *T* and sometimes *U* waves. The typical ECG outline is appeared in Fig. 1. The *P* wave represents the atrial depolarization. The QRS complex represents the ventricular depolarization. The *T* wave represents the repolarization of the ventricles. It follows each of the QRS complexes. Normally, it is isolated from the QRS by a steady interval [3].

The reported work is to read the JPEG form of ECG, from the printed form of ECG and to convert that image to digital time series signal. The conversion procedure involves image processing approach for converting the scanned image into digital signal form by using morphological operations and skeletonization technique.

Fig. 1 Typical ECG waveform



2 Literature Review

ECG is a noninvasive, transthoracic diagnostic technique. Usually, 12-lead ECG signal is used for the diagnosis of heart. There are 12 different segments. They are limb leads (1, 2, and 3), chest leads ($V1$, $V2$, $V3$, $V4$, $V5$, and $V6$), and peripheral leads (aVR, aVL, and aVF). The limb lead consists of four leads. They are located on the left and right wrist, followed by left and right ankle. The lead connected to the right ankle is a neutral lead. The six leads which are labeled as 'V' leads are positioned on the rib cage. The generated ECG signal using 12 leads is traced on a thermal paper using stylus. It is difficult to keep the paper-recorded signals as the number of patients is increasing day by day, and also it takes lot of storage space. In order to check the records as and when required, they are scanned and stored in the electronic devices such as computer in the form of PDF files or JPEG images. This form of ECG has to be digitized in order to get the extracted signal so that it can be used for further process such as QRS complex detection [1].

In the study of digitization of paper-recorded ECG, MATLAB is used to change the ECG data from paper printout into digital signals. A strategy is built that includes preparing of ECG paper records by an effective and iterative arrangement of digital image processing methods. The transformation of ECG image information to digital signal brings about less storage and less recovery of data. In this study, the methods like de-skewing, enhancement of image, color-based segmentation, and region-based segmentation, signal representation and filtration have been used. De-skewing uses Hough transform, and it is done to rotate the image. The color image segmentation techniques used here are to segment the set of ECG wave region. This can be used in ECG wave analysis and detection application. This technique also involves the binary image as preprocessing [4].

In general, there are three types of ECG paper charts which are divided upon their backgrounds: uniform background, background with colored grid and with black grid. The developed algorithm consists of morphological operations to retrieve ECG data present in the image. The results show that the method erases the background noise and acquires the digital ECG signal from ECG paper [5]. A binary image of the ECG record is found by applying thresholding technique. It is applied to remove the background grid present in the image. It is also applied in order to get the digitized signal by determining the pixel scale. Automatic methods used in the process will make the analysis easier by detecting the characteristic waves in simpler way. In addition, these files contain one-dimensional signals which are smaller in size compared with the image ones. This will help in simplifying the patients' record storage space [3].

From the past few years, several researchers have been working on developing the accuracy of the conversion of the ECG image. Mainly, all researchers are trying to reduce the time of execution for the conversion of image to digital signal. Some of these methods had a few drawbacks such as less accuracy, high computational time, or more manual interaction. In order to overcome these drawbacks, the new technique which involves image binarization, morphological operations, and some filtering techniques have been used.

3 Methodology

Considered printed thermal paper of ECG with 12-lead signal is recorded at 25 mm/s. In order to convert the ECG paper image to a digital signal, it is necessary to convert the paper to image form. In order to convert the paper-printed ECG to JPEG form, first need is to scan the paper. During digitization, ECG scan will resample the waveform. Also it rescales the digitized waveform to the required sampling rate. It also helps in calculating the amplitude resolution [6]. The flow diagram for digitization of the ECG image is shown in Fig. 2.

After scanning the ECG paper, first step is to binarize the scanned image of ECG in order to get the image in terms of 0's and 1's. This will help in finding the pixel values in the binarized form. The flow diagram of the binarization process of scanned ECG image is shown in Fig. 3.

Thresholding converts over an information set containing values that shift over some range into another information set containing values that differ a smaller range [6]. Thresholding is used to find binary images from a gray scale image.

Let the image intensity be $I_{i,j}$. If $I_{i,j}$ is less than some fixed constant, then the image is replaced as black pixel or else as white pixel. This can be done by known gray levels. Thresholding is defined as an operation that involves test against a numeric function T [7]

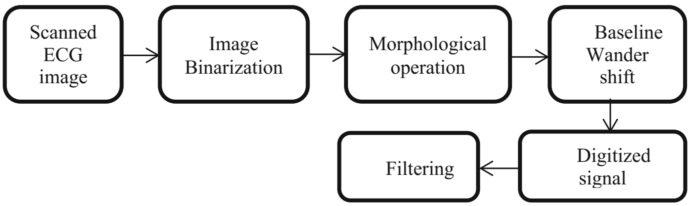


Fig. 2 Flow diagram of digitization algorithm

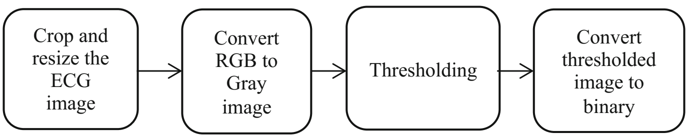


Fig. 3 Flow diagram of the process of binarization operation

$$T_0 = T\{X, Y, P(X, Y), f(X, Y)\}, \tag{1}$$

where $P(X, Y)$ represents local property of the point (X, Y). The resulting thresholding image $g(X, Y)$ is then defined as:

$$g(x, y) = \begin{cases} 1 & \text{if} \quad f(X, Y) > T_0 \\ 0 & \text{if} \quad f(X, Y) \leq T_0 \end{cases}. \tag{2}$$

Binary image is also a digital image. It has two possible values for each pixel. It is referred as an image, since it takes just binary digital to represent the every pixel. The binarized image from the scanned ECG image is then morphologically processed in order to find the skeleton of the binarized ECG image. The morphological operations that are carried out in this work are erosion, dilation, and skeletonization. Figure 4 shows the flow diagram of morphological operations carried out in this work.

Erosion is the key operation for all the other morphological operations involved in the technique of morphological image processing. In binary image morphology, the image is considered as a subset of a Euclidean space. The fundamental is to test the image with a simple and with the pre-characterized shape of the image. Let A be a binary image in the given Euclidean space E. Let B be the structuring element for A. The erosion of A by B is defined as:

$$A \ominus B = \{z \in E | B_z \subseteq A\}, \tag{3}$$

where B_z is the translation of B by vector z:

$$B_z = \{b + z | b \in B\}, \quad \forall z \in E. \tag{4}$$

Dilation is an essential operation in a mathematical morphology. It uses structuring element for examining and extending the shapes of the input image. In binary image morphology, it works as a shift-invariant operator. The dilation of A by B is defined as:

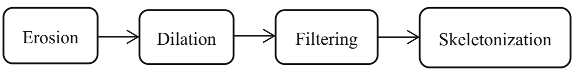
$$A \oplus B = \left\{z \in E \middle| (B^s)_z \cap A \neq \emptyset\right\} \tag{5}$$

where B^s denotes the symmetric of B, that is

$$B^s = \{x \in E | -x \in B\}. \tag{6}$$

A morphological skeleton technique is used to find the skeletal version of the image. Morphological skeletons can be of two sorts, and the first one is characterized by method for morphological openings to form the original shape. Another

Fig. 4 Flow diagram for skeletal image of ECG



alternate method, suggested to use, is hit-or-miss transform. In this reported work, the method of morphological openings is used for the reconstruction of ECG from the printed form of the ECG. The idea of skeleton $S(A)$, which is a subset of A, is naturally simple. Consider a point z in $S(A)$. $(D)_z$ is the largest disk in A, and it is called as maximum disk. The $(D)_z$ touches the boundary of A at two or more different locations [7]. The skeleton of A is expressed in terms of erosions and openings.

$$S(A) = \bigcup_{k=0}^{k} S_k(A). \tag{7}$$

The skeletonized image of ECG is then used to find the end points and the branch points of the skeletal image. These two points are then cascaded, and again the image is regenerated. This regenerated image will have some information loss. This regenerated image is the de-masked using geodesic distance transform. Geodesic distance transform is mainly used for binary images. The skeletal image formed is also a binary image, so this transform can be used to compute the distance between the binary image that is skeletal image and seed locations specified by the mask. Also the distance between the branch point and end point is calculated in order to find de-mask of the skeletal image. The difference between the de-masked image and the skeletal image of ECG will help in getting the digitized signal.

In instances where a constant, linear, and curved offset is available, detrend technique is used to expel these impacts. Detrend fits a polynomial of an offered request to the whole digitized ECG signal and subtracts this polynomial. This calculation fits baseline points in the signal. This calculation also fits the polynomial to all points, baseline, and the signal. It tends to work just when the biggest source of signal in every sample is background obstruction. In estimations, the detrending tends to evacuate varieties which are valuable in demonstrating. They even make nonlinear reactions from generally direct ones.

Furthermore, the way that an individual polynomial is fit to every range expands the measure of meddling difference in an information set. Because of these reasons, usage of detrend is recommended just when the general signal is controlled by backgrounds which are for the most part similar shape. Normally, the baseline is approximated by lower order polynomial. A particular baseline reference is provided in order to shift the signal to that baseline. This baseline reference is referred as 'basis.' When the basis is given, the background will be evacuated by subtracting each of these bases to acquire a low background result. The result found by detrend technique is without negative peaks.

Smoothing is a low-pass filter. It is used for expelling the high-frequency noise from the digitized ECG signal. This is done independently on every line of the information grid. It accepts that the factors which are close to each other in the information grid are identified with each other and contain comparable data which can be arrived at the midpoint of together to remove noise without critical loss of the signal of interest. The implemented smoothing is the Savitzky-Golay (SavGol) algorithm. The algorithm basically fits singular polynomials to windows around every point in the range. These polynomials are then used to smooth the information. The calculation requires choice of both the extent of the window that is the channel width and the order of the polynomial. The bigger the window and lower the polynomial order, the additionally smoothing happens. The algorithm approximates and removes some abnormal components present in the ECG signal.

The performance of the algorithm is evaluated with the root-mean-square error (RMSE) measures. That is the error between the binarized and the skeletal form of ECG image is found. The error is found by subtracting these two images. The RMSE is computed for n different predictions, and here the predicted value is $\hat{x}_t$ for times t and a dependent variable x_t.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{t=1}^{n} (\hat{x}_t - x_t)^2}{n}}. \tag{8}$$

4 Result Analysis

The proposed algorithm is applied on a scanned ECG paper of a patient of 46 years old of a male sex, by using all the 12 segments from the 12-lead ECG recording. Proposed method of skeletonization of signal contains high-frequency noises. In order to remove the noise present in the signal, filters are applied. The accuracy of the found result is done by calculating the root-mean-square error between the binarized image or original image and the skeletonized image. RMSE is applied only to check that the resultant signal found in this project is almost same as that of the original scanned document.

Usually, ECG is printed on a thermal paper. And this thermal paper is scanned and stored in the form of JPEG files, and these files are given as an input for the digitization process. The image of scanned ECG printout which is given as input is shown in Fig. 5. Among 12-lead image, only lead 2 has been selected and the cropped form of input image is shown in Fig. 5.

The scanned image is in the color form. To discretize the waveform present in the image, the image is converted to gray scale format. The conversion of color image to gray scale form is shown in Fig. 6a, b. This gray scaled image is then converted to binary image by applying a suitable threshold. The values of binary image will be in terms of 0’s and 1’s. The values above threshold will write as 0 s. Find the pixel values in terms of 1 and 0 s. The binarized image from the gray scale image is shown in Fig. 6c.

Morphological operations include erosion and dilation. The result of erosion operation on the binary image tends to loss of information present in the image. During this process, the upper and lower limit in the Cartesian coordinates are recorded. In order to make the image signal even, filtering is applied. Figure 7 shows the eroded, dilated and filtered, and the complement of the filtered image.

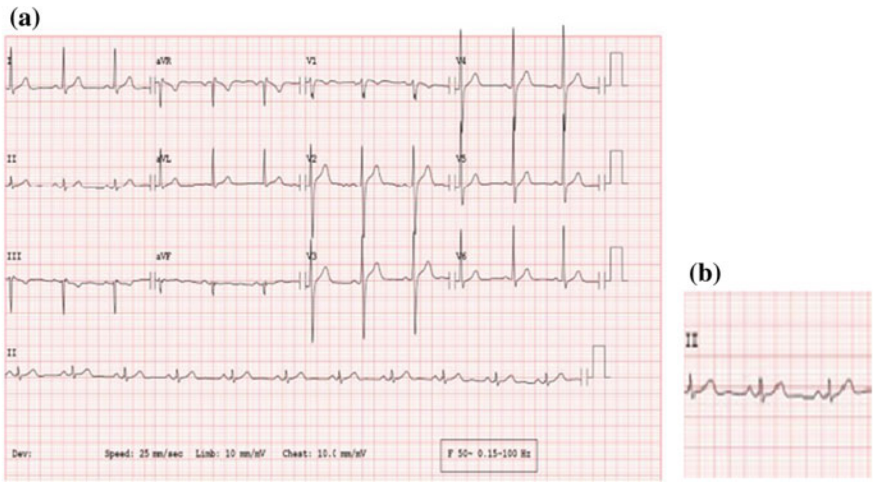


Fig. 5 **a** Scanned image of ECG with 12 segments as input and **b** cropped image (*Source* Adapted from Philips, CHC Hospital, Hebri)

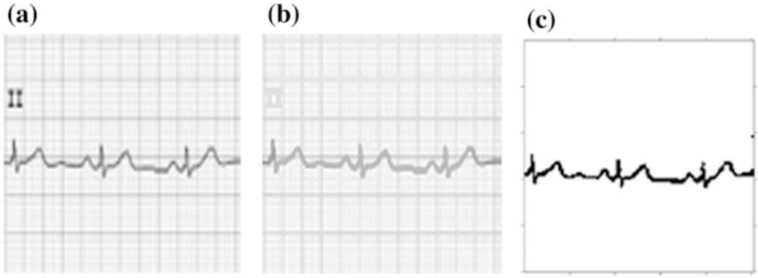


Fig. 6 **a**, **b** Gray scale and **c** binary form of image

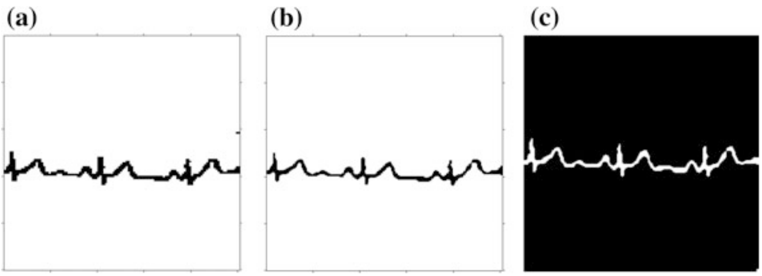


Fig. 7 **a** Eroded image, **b** dilated image, and **c** complement of filtered image

The image formed by the above method has two edges. In order to get the digitized signal, there must be only one edge. Thus, skeletonization method helps us in finding the mean of the two edges of the binarized signal image. The branch points and end points of the skeletonized ECG image are shown in Fig. 8. By cascading the branch point image and end point image, we get the thinned skeletonized image. Figure 8c shows thin skeletal of the binarized ECG image.

The waveform of ECG is categorized by black pixels. The locations of the pixels are denoted by *x*-*y* Cartesian coordinates. The image shown in Fig. 9a is the

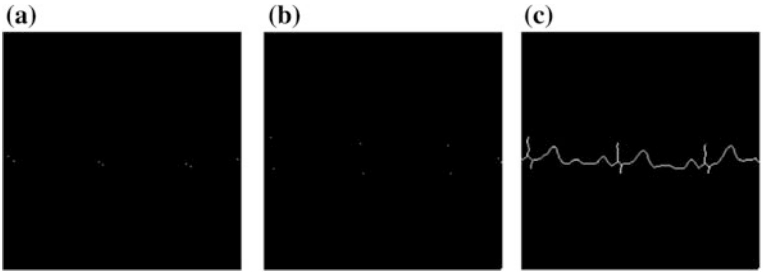


Fig. 8 **a** Branch points, **b** end points, and **c** thin skeletal image of ECG

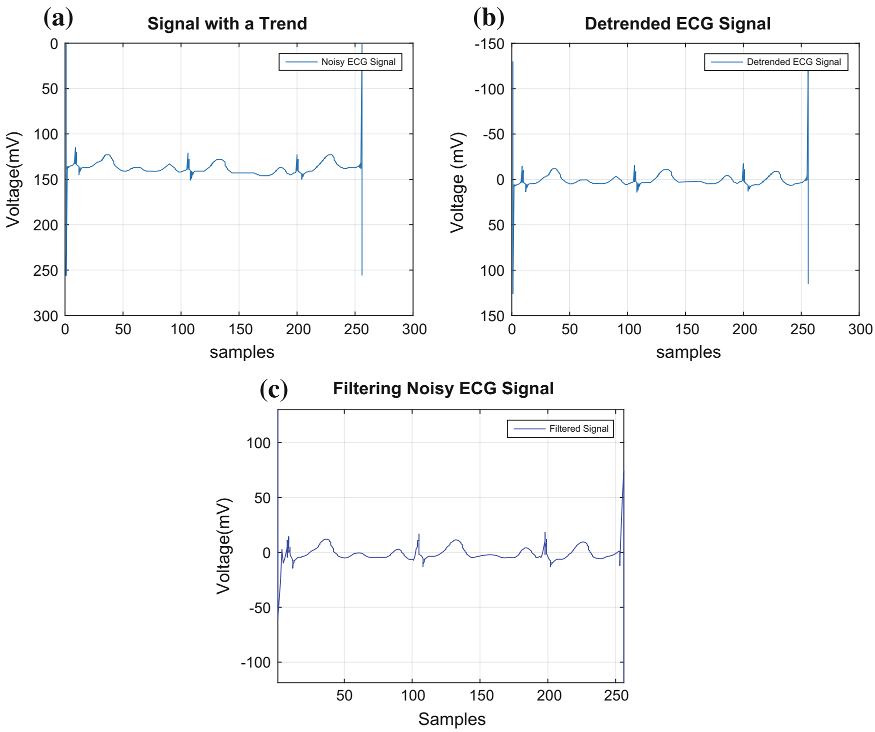


Fig. 9 **a** Digitized signal and **b** detrended signal, and **c** filtered signal

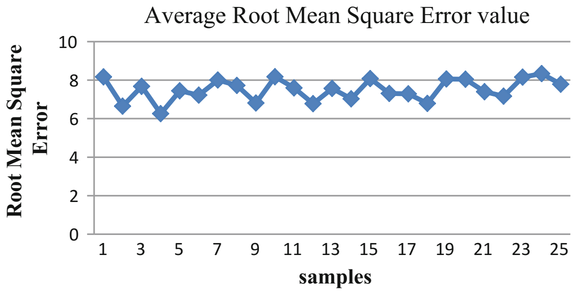


Fig. 10 Average root-mean-square error of the 25 samples

Table 1 RMSE between the skeletal image and the binary images of different patients

Root-mean-square error (RMSE)													
Patient	Leads			aVR	aVL	aVF	*V*1	*V*2	*V*3	*V*4	*V*5	*V*6	Mean RMSE (%)
	1	2	3										
*P*1	6.84	6.77	10.2	5.96	10.7	7.99	9.19	8.29	8.21	7.51	8.39	8.12	8.17
*P*2	6.45	6.10	5.97	6.88	8.87	6.62	6.55	6.40	7.45	6.62	5.89	5.94	6.65
*P*3	6.24	7.52	7.17	8.83	6.09	9.18	9.84	9.40	7.62	5.92	8.04	6.42	7.68
*P*4	5.83	6.49	6.41	6.04	5.79	6.50	7.19	6.10	6.55	6.14	6.07	6.06	6.26
*P*5	7.95	8.30	7.69	7.37	8.70	8.79	7.19	6.33	8.26	6.96	6.10	5.79	7.45

transformed signal from image form to Cartesian coordinates. The time and voltage values are obtained by first setting the *y*-axis reference.

The signal found here is of noisy signal. Especially, QRS complex has lot of disturbances. So there is a need to make that signal noiseless using filters. In order to find the true amplitude of the signal, the baseline is needed to be shifted to ‘0’ level and that it is filtered to remove the noise especially present in the QRS complexes. The shift of the signal to a particular basis is shown in Fig. 9b. Figure 9c shows the filtered image using smoothing.

The comparison between the digitized signal and the binarized image is found by using point-by-point verification methods. It is confirmed by calculating the root-mean-square error (RMSE) between the skeletal and the binary images of ECG.

Table 1 shows the RMS error values for the 12 chosen recordings. This explains the small error between the skeletonized and binarized image of ECG.

Table 1 shows that RMSE values for different patients are very less. Totally, 25 patients’ report was taken and all the records taken here were all have age above 45 years. There were 11 male records and 14 female records. Figure 10 shows the average root-mean-square error chart for all the 25 samples. The average RMS error found is 7.5%.

5 Conclusion

The developed algorithm converts a 12-lead ECG image to digital signal. All the 12 segments in the image do not contain same shape of ECG waveform. In order to find the digital signal of whole image, a part by part or each single segment has to be taken one after another. That means at a time only one segment is executable. This is the main disadvantage of the work. But the advantage of this project is that by executing the each segment individually, the accuracy of getting the digitized signal is more. Other than this, the digitized signal gives the accurate signal or similar signal as that of the original signal in the image. Here, the skeletonization technique used will help in the conversion process. And also it makes the algorithm very simple. If an algorithm is simple, then the execution time will also be less. So the execution time taken for this algorithm is very less. The digitized signal derived can be further used for the detection of *P*, *T* waves and QRS complex of the ECG signal. All these detections will help in the classification of ECG signal.

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