Research on Machine Instrument Panel Digit Character Segmentation

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ABSTRACT

In this study, the authors perform slant correction on fixed-format dial images using the Hough transform, followed by their "scaling" using binary wavelets to achieve coarse segmentation for characters or numbers. Simultaneously, they propose a binary threshold iteration method that accurately determines the position of each character or number even in the presence of adhesion or fragmentation, enabling precise segmentation. They employ their proposed approach to segment digits and characters displayed on 98 fixed-format dials. Experimental results demonstrate a recognition rate of 98.5% for both letters and numbers, highlighting significant practical value and real-world implications.

KEYWORDS

Character Segmentation, Machine Dial Images, Research

INTRODUCTION

In recent years, number and character recognition has been gaining widespread attention in the field of image processing, thanks to the rapid development of digital technology. The segmentation of numbers and characters in dial images is a popular research directions in this field. Dials are widely used in instruments, automotive dashboards, and other fields, making it essential to accurately segment numbers and characters for improving recognition accuracy and practical applications. This study aims to achieve precise segmentation of characters and numbers in dial images using methods such as the Hough transform and binary wavelets, providing effective technical support for related applications (Fu et al., 2001).

There have been noteworthy research results in the field of digit and character segmentation, we present an overview of noteworthy research results in the field of digit and character segmentation from 2021 to 2023, covering various methods and techniques. The method proposed by Li and Dong (2022) utilizes a segmentation approach based on nearest neighbor values and prior knowledge of license plate characters to obtain the first five complete characters of a license plate. The remaining five characters of the license plate are obtained through character concatenation based on an enumeration method, achieving a complete license plate segmentation.

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Wang and Li's (2023) method first used ROI regions and then connected component processing algorithms on images of exam paper score columns, which are acquired using a high-resolution scanner. The abbreviation "ROI" stands for "Region of Interest," referring to specific areas in an image or graphic that are of particular interest or focus for processing. This process extracts handwritten scores, forming individual images, which are then normalized and formatted into a CSV file. These data are fed into a pre-trained LeNet-5 network for recognition. During the training of the LeNet-5 network, parameters such as batch size, learning rate, epochs, and weight quantities are continuously adjusted, resulting in a recognition accuracy of 93.2% (Wang & Li, 2023).

In this study, we first use the Hough transform to perform skew correction on dial images with fixed formats. Subsequently, we employ binary wavelets to "scale" the images, achieving coarse segmentation of characters or numbers. Additionally, we propose a binary threshold iteration method to accurately determine the position of each character or number even when it undergoes adhesion or fragmentation, which results in precise segmentation. The results show that the proposed method achieves a recognition rate of 98.5% for both letters and numbers in 98 fixed-format dial images, validating its efficiency and accuracy. It can provide strong support for the practical application of character and number segmentation technology.

CHARACTER SEGMENTATION TECHNOLOGY

Introduction to Character and Number Segmentation Technology

Overview of Character Segmentation Techniques

A core aspect in character recognition systems is that most of the existing recognition methods focus on isolated character recognition. An essential aspect of character recognition is character segmentation, and incorrect character segmentation directly leads to character recognition errors. Therefore, character segmentation technology is essential for successful character recognition (Zheng et al., 2021). Character segmentation is defined as the technique of decomposing an image containing a character sequence into sub-images with isolated characters. It emerged in the 1970s when a single-character image database was used as the recognition target. Due to insufficient recognition of the importance of character segmentation in commercial applications, the development of character recognition systems remained stagnant at this stage and did not receive a significant amount of attention. In the 1980s, with the increasing commercial applications and widespread attention dedicated to character recognition, research on character segmentation technology underwent extensive and in-depth development (Qian & Bai, 2021).

Generally, in character recognition systems, there are handwritten and printed characters based on different recognition processing objects. Since the 1970s, various character segmentation methods have emerged, such as region segmentation, merging, and projection. The distinction between printed and handwritten characters lies in the fact that the former use fonts or similar fonts during printing. Printed text is relatively standardized along both horizontal and vertical orientations, making it widely applicable. On the other hand, handwriting is practiced by people in their daily lives, and handwritten text cannot be passed down and processed without printing technology (Hu et al., 1999).

Progress of Character Segmentation Technology

The printed and handwritten character texts require segmentation of fixed-spacing text, segmentation with sticky characters. The cropping method based on vertical projection is a technique for segmenting text with fixed character spacings. This method can segment each text into characters, ensuring that the resulting segmented text conforms to the character text without any breakage, adhesion, or other phenomena. However, in reality, the presence of adverse conditions like noise makes it rare to encounter text that is not fragmented or stuck together. Therefore, it is necessary to study feature segmentation under fragmented and adhered conditions (Liu et al., 2022).

The following will analyze key issues encountered in the separation of cohesive characters, including:

- Occurrence of adhesion between characters.
- Identification of the splitting point if separation is needed.

The segmentation of cohesive characters can be classified into two methods: feature-based and recognition-based. In feature-based segmentation, the vertical projection is first transformed into a second-order difference function that directly provides information for locating breakpoints. This method involves analyzing characteristics such as character height, aspect ratio, width, pixel density, candidate points, and contour analysis to determine the segmentation points. Recognition-based segmentation, on the other hand, is an interactive closed-loop method where segmentation and recognition stages influence each other. This approach utilizes a moving window for recognition, creating a closed-loop system with segmentation. The final determination of segmentation points is made through multiple phases of decision-making based on the recognition results (Chen & Ding, 2002).

Methods for Segmentation of Broken Characters

There are two methods, described as follows:

- A comprehensive processing method for spacing, width, and other information between characters.
- A comprehensive processing method based on recognition results that consider character elements.

For the segmentation of characters in a fixed format, the consideration extends beyond stroke breaks and cohesion between characters; there is also the challenge of contamination, skewness, and connections to other positions within the overall fixed-format characters. Consequently, character segmentation in fixed-format scenarios is more challenging than general text character segmentation. Relying solely on the vertical projection method for character segmentation falls short of achieving ideal segmentation. Hence, a segmentation algorithm tailored for fixed-format characters is proposed—directly projecting the image vertically and employing fixed proportions such as height, width, and spacing relationships between fixed-format characters for segmentation. This method includes the following steps:

- Establishing the fixed-format boundaries, then employing Freeman code tracking techniques to eliminate separators, as well as removing other fixed disturbances.
- Using fixed-format horizontal and vertical projections to eliminate the effects of remaining boundaries and other fixed interferences.
- Determining the upper, lower, left, and right boundaries of the characters, and extract individual characters.

The above-mentioned method yields good results for general fixed-format character segmentation. However, a particular scenario exists that can affect the overall segmentation effectiveness—the skewed fixed-format segmentation issue, especially in the segmentation of data representing “1.” Therefore, improvements are made to the binarization algorithm, specifically in handling binary image methods that might impact the accurate selection of segmentation points. In the next section, we will delve into the research of the aforementioned approach. It currently is unclear what the lists is meant to represent.

1. Use a simplified Hough transform to correct the skew of the fixed-format dial.
2. Perform multi-scale signal retrieval and automatic signal amplification using wavelet analysis. At the same time, the knowledge of the fixed-format dial is used to filter the vertical projection of the fixed-format dial, search for special slot points, and designate them as candidate segmentation points.

3. Fixed-format dial candidate segmentation points that are prone to adhesion and damage are adaptively searched using a binary threshold iteration method to segment the areas where individual characters are located.
4. Constructing characters from the individual character regions mentioned above: (a) multi-line vertical projection;(b)Precisely locating character boundaries; (c) extracting individual characters.

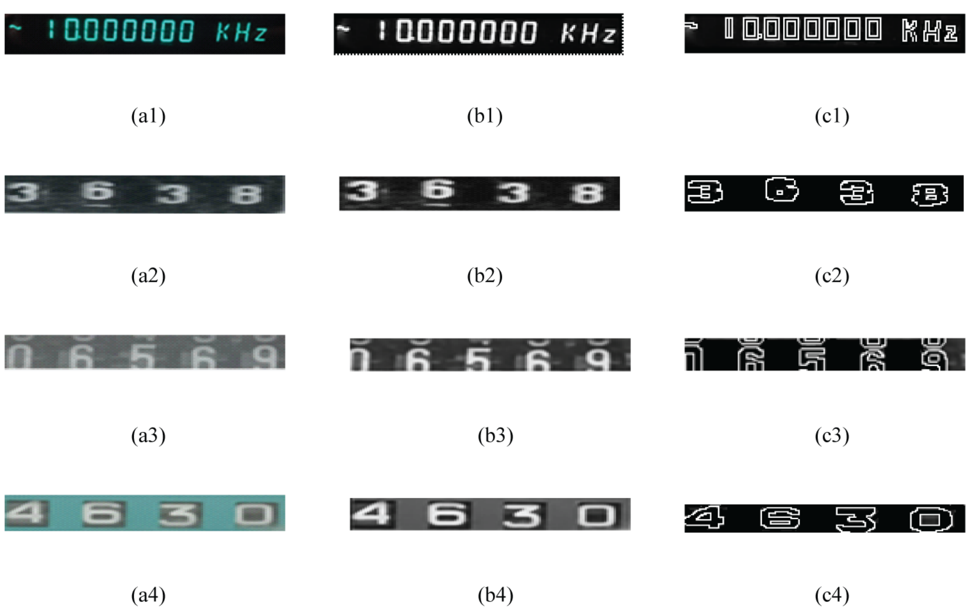
Hough Transform Under the Fixed Format Dial Tilt Correction

The face frame of a fixed-format dial is rectangular, but due to the machine's data collection angle and potential tilting of the fixed-format dial, it may appear as an approximate rectangle or even a trapezoid in the image. The character spacing within the fixed-format dial face frame is very small. Experimental verification indicates that when the inclination angle of the fixed-format dial face frame is >=2 º, it can adversely affect subsequent character segmentation rates and character recognition rates. In the following illustration, with an inclination angle of 5 ºfor digital oscilloscopes, digital low-frequency signal generators, digital multimeters, and digital voltmeters, it is evident that selecting segmentation points becomes challenging. Even if segmentation succeeds, the positions are offset, significantly impacting accurate recognition and diminishing the success rate (Shi et al., 2020).

In summary, it is necessary to perform skew correction on the image of the fixed-format frame before segmenting the data in the fixed-format dial.

The images in Figure 1 reveal that the dials of the digital oscilloscope, digital low-frequency signal generator, digital multimeter, and digital voltmeter are mainly categorized into several types,

Figure 1. Fixed format meter panel (low-frequency signal generator, digital meter) original drawing, binary drawing, and other illustrations



Note. (a1) Original image of the low-frequency signal generator**;** (b1) Binarized image of the low-frequency signal generator; (c1) Edge detection image of the low-frequency signal generator; (a2) Original image of the digital voltmeter 1; (b2) Binarized image of the digital voltmeter 1; (c2) Edge detection image of the digital voltmeter 1; (a3) Original image of the digital voltmeter 2; (b3) Binarized image of the digital voltmeter 2; (c3) Edge detection image of the digital voltmeter 2; (a4) Original image of the digital voltmeter 3; (b4) Binarized image of the digital voltmeter 3; (c4) Edge detection image of the digital voltmeter 3.

such as black background with white text, black background with green text, green background with white text, and so on. There is a distinct grayscale contrast between the background and the numbers or text. Therefore, after binarization, only black and white pixels will remain, representing the background and the numbers or text.

Borders with numbers or text are typically processed using white pixels as the standard. This refers to the fixed-format dial face frame's numbers, letters, and borders represented by white pixels. However, if it involves a yellow background with black text or a black background with red text, it is usually based on black pixels. Boundary tracking searches are employed to determine the contours, followed by an inversion process to achieve the desired effect.

After edge detection, the edge image (as shown in Figure 1, c1-c4) reveals that the border lines of the fixed-format dial face frame are longer vertically than the character lines. Consequently, by calculating the inclination angle of the lines reaching the borders, one can correct the skewed fixed-format dial face frame. This method is particularly effective in correcting the inclination of fixed-format dial borders.

The effective method for detecting straight lines is the Hough transform, which is based on its accuracy, simplicity, and strong practicality, leading to successful applications. Therefore, considering the actual conditions of a fixed-format dial face frame, the Hough transform is applied for simplification and improvement.

The Hough transform method applies global image characteristics to directly detect target contours, based on the common approach of connecting edge images to form closed boundaries (Zhong et al., 2022). Under the condition of known a priori safe Erlanger shapes, applying the Hough transform conveniently obtains closed curves while connecting discontinuous edge pixels. The significant advantage of the Hough transform is its minimal susceptibility to curve interruptions and noise impact (Qin & Yang, 1998).

The concept of the Hough transform is based on the duality of points and lines. Before the image transformation, Hough transform is in the image space. After the image transformation, Hough transform is in the parameter space.

In the image space MN, a straight line can be represented as:

$$n = k\,m + d \tag{1}$$

In the above expression, k is the slope and d is the intercept. Therefore, for the points (m_p,n_p) and (m_q,n_q) on in the image space MN, there exists:

$$n_{p = k}\ m_{p + d;}\ n_{q = kq + d} \tag{2}$$

The above expression can be represented as:

$$d = -\,k\,m_p + n_{p;\,d} = -\,k\,m_q + n_q \tag{3}$$

In the parameter space K D formed by parameters k, d, the equations of the two lines mentioned above represent two intersecting lines. The intersection point is represented by (k', d'), denoting the slope and intercept values of the lines in the image, respectively.

From the above, it can be understood that the Hough transform finds the intersection points of the line bundles in the parameter space that corresponds to edge segments in the image space and thus obtains the line equation parameters of the edge segments in the image space. For the fixed-format dial frame images, the line bundles with the maximum number of intersections in the parameter space correspond to the points with the most collinear occurrences in the image space. The aforementioned line corresponds to the position of the frame (Zang et al., 2019). Due to the varying research subjects, consideration of computational accuracy and workload is crucial. Therefore, the application involves using the polar coordinate linear equation for target pixel-by-pixel scanning. The process is as follows:

1. After performing edge detection on the binary image of the fixed-format dial frame, the resulting edge image M is obtained. In this context, considering both operational speed and comprehensive useful information, the noise positions located 3/5 from the bottom of the fixed-format dial frame image are chosen as the origin. The horizontal direction to the right is set as the positive direction of the M-axis, and the vertical direction upwards is set as the positive direction of the N-axis. This is done to detect the coordinates (m, n) of the target pixels.
2. Assume a set of linear equations $\varphi = \upsilon 1 \sim \upsilon 2$. As the inclination angle of the fixed-format dial frame usually does not exceed ±30º, set $\upsilon 1 = 60º$ and $\upsilon 2 = 120º$ based on geometric knowledge:

$$m * \cos\varphi + n * \sin\varphi \tag{4}$$

Formula (4) is employed to capture the geometric aspects related to the inclination angle of the fixed-format dial frame.

Let f be any projection of an object onto an image, i.e., points K(m, n) on the line assembly. It can be written as:

$$f = m * \cos\varphi + n * \sin\varphi \tag{5}$$

Let the cumulative array B(φ) be used to record the number of collinear points, i.e., the number of target pixels satisfying the above formula. We can calculate the following:

$$r = \max\{B(\varphi),\ \varphi \in [\upsilon_{1,} \upsilon_{2}]\} \tag{6}$$

The corresponding tilt angle is the angle from the origin to the nearest vector of the inclined line of the fixed-format dial φ bezel. Therefore, the rotation angle ε of the fixed-format dial panel can be calculated as ε = 90º- φ . The corrected image with the tilt appears in Figure 2.

The above instructions will correct for a watch dial that is titled in a fixed format. Another scenario may arise due to the angle of the capturing machine used for collecting data in the specified fixed format. To eliminate the aforementioned tilt correction, adjust the angle of the capturing machine to an appropriate horizontal position.

"Zoom" Method of Binary Wavelet

In adaptive threshold selection, we employ binary wavelet transform, which is essentially a discrete wavelet transform. It can be written as "Discrete," which refers to continuous scale parameters δ and continuous translation parameters η. It does not refer to the time variable h.

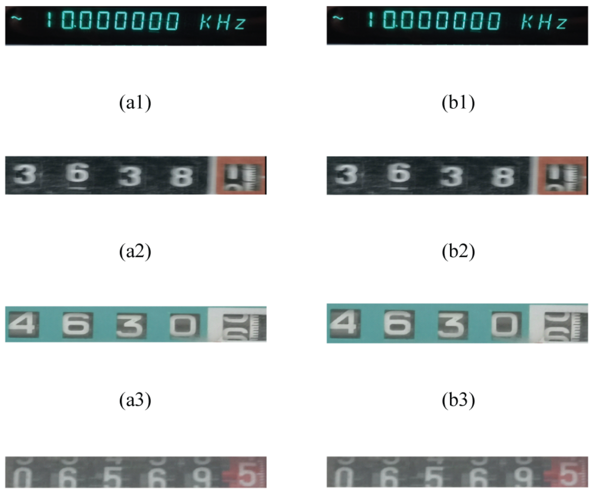
It can be observed that the above features differ from the usual time discretization.

The mathematical expression of the binary wavelet transform is as follows: First, a continuous wavelet discretization is performed and, subsequently, discrete parameters are selected.

Let the condition be: In the continuous wavelet, the function is:

$$\psi_{\delta,\eta}\left(h\right) = \left|\delta\right|^{-1/2} \psi\left(\frac{h-\eta}{\delta}\right) \tag{7}$$

Figure 2. Fixed format dial panel (low frequency signal generator, digital meter diagram) original and corrected images



(a1) (b1)

(a2) (b2)

(a3) (b3)

(a4) (b4)

Note. (a1) Original digital electric meter image; (b1) Image after correction; (a2) Original digital electric meter image; (b2) Image after correction; (a3) Original digital electric meter image; (b3) Image after correction; (a4) Original digital electric meter image; (b4) Image after correction.

In the above equation, $_{\eta}\in G$, $\delta \in G^{+}$, Let $\delta \neq 0$, ψ be admissible.
Therefore, in discretization, the ultimate limit of δ can only be positive:

$$S_{\psi} = \int_{0}^{\infty} \frac{\left|\hat{\psi}\left(\bar{\upsilon}\right)\right|}{\bar{\upsilon}} d\bar{\upsilon} < \infty \tag{8}$$

Typically, the discretization of scale parameter δ and translation parameter η for continuous wavelet transform can be described as:

$$\delta = \delta_{0}^{q} \tag{9}$$

$$\eta = e\delta_{0}^{q}\eta_{0} \tag{10}$$

In (9) and (10), $q \in O$, and the expansion step $\delta_{0} \neq 1$ is a fixed value. For ease of computation, we assume $\delta_{0} > 1$.
Hence, the corresponding discrete wavelet function $\psi q,e(h)$ can be written as follows:

$$\psi_{q,e}\left(h\right) = \delta_{0}^{-q/2}\psi\left(\frac{h - e\delta_{0}^{q}\eta_{0}}{\delta_{0}^{q}}\right) = \delta_{0}^{-q/2}\psi\left(\delta_{0}^{-q}h - e\eta_{0}\right) \tag{11}$$

Subsequently, the discrete wavelet transform coefficient is:

$$S_{q,e} = \int_{-\infty}^{\infty} f\left(h\right)\psi_{q,e}\left(h\right)dh = f, \psi_{q,e} \tag{12}$$

The above reconstruction formula can be written as:

$$f\left(h\right) = C\sum_{-\infty}^{\infty}\sum_{-\infty}^{\infty} S_{q,e}\psi_{q,e}\left(h\right) \tag{13}$$

C: Constant unrelated to the signal.

In conclusion, we have obtained the discrete form of the wavelet transformation. As the wavelet transformation has variable frequency/time resolution and is suitable for analyzing non-stationary signals, the values of continuous translation parameter η and continuous scale parameter δ should be changed to provide the wavelet transform with a 'zoom-in' capability. This is achieved by selecting a dynamic sampling grid in practice. It is represented as follows:

$$\delta 0 = 2 \tag{14}$$

$$\eta 0 = 1 \tag{15}$$

For each grid point mentioned above, the corresponding scale is 2^q, and the translation is $2^q e$. Therefore, the wavelet is given by:

$$\psi_{q,e}\left(h\right) = 2^{-q/2}\,\psi\left(2^{-q}h - e\right) \tag{16}$$

The above wavelet is referred to as a binary wavelet (Wang & Wang, 2022) where q,e ∈ O.
The zooming function is a characteristic of signal analysis using binary wavelets.
Therefore:

- Assuming a portion of the observed signal is magnified by a factor of 2^{-q}, If more signal details are required, the magnification should be increased by decreasing the q value.
- If the information about the coarser contents of the signal is required, the magnification can be decreased by increasing the q value.

From the above description, it is evident that the 'mathematical microscope' is a characteristic description of wavelet transformation.
In conclusion, we define it as follows:

Definition: Let$_{\psi q,e}$(h) ∈ R^2 (G). If there exist constants B and I, and $0_< B_< I_< \infty$, the stability condition holds almost everywhere and it can be represented as:

$$B \leq \sum_{q \in 0} \left| \hat{\psi}\left(2^{-q} v\right) \right|^2 \leq I \tag{17}$$

where $_{\psi q,e}$(m) is a binary wavelet.

Exist: $\left\{M_{2^q} f\left(e\right)\right\}_{e \in 0}$: The sequence of functions is referred to as the binary wavelet transform of f:

$$M_{2^q} f\left(e\right) = f\left(h\right), \psi_{2^q}\left(e\right) = \frac{1}{2^q} \int_G f\left(h\right) \psi^*\left(2^{-q} h - e\right) dh \tag{18}$$

The inverse transform of (9) can be expressed as follows:

$$f\left(h\right) = \sum_{q \in 0} M_{2^q} f\left(e\right) * \psi_{2^q}\left(h\right) = \sum \int M_{2^q} f\left(m\right) \psi_{2^q}\left(2^{-q} h - e\right) de \tag{19}$$

Clearly, the binary wavelet transform is distinct from the continuous wavelet transform; the binary wavelet transform discretizes only the scale parameter while maintaining continuous variation in the translation parameter in the time domain.

In conclusion, the binary wavelet transform avoids any distortion of the signal under the condition of time-domain translation invariance. This is a specific advantage of its application, allowing for in-depth research.

Exploration of Character Segmentation Algorithm Based on Wavelet Analysis

For the segmentation of numbers and letters on a fixed-format dial, the key lies in selecting effective segmentation points (Sun et al., 2022). Therefore, a segmentation point selection method based on multi-scale wavelet analysis is proposed.

The process of representing from coarse to fine involves determining a limited number of trough points (candidate segmentation points) for vertical projection points in image, based on the optimal scale conditions. The segmentation points of the boundaries are determined based on the aspect ratio features of characters and numbers. The character segmentation process using the panels of a low-frequency signal generator and a digital meter is explained below.

Low-Frequency Signal Generator

- Typically, the display panel of a low-frequency signal generator is 19mm high, 192mm wide, 160mm long, and has a 5mm gap between each character.
- Each individual digit has a uniform width of 8mm and a height of 16mm, with an aspect ratio of 2:1.
- In displays, there are typically 12 numbers or letters; when comparing the panel with the edges, if the grayscale of the numbers differs from that of the background, then after binarization, the texture features of the numbers become very pronounced.

The above discussion shows that the digits of the low-frequency signal generator can serve as a basis for character segmentation. The following points should be considered for achieving effective segmentation of digits:

- Comprehensive information regarding the low-frequency signal generator.
- Objective factors such as the quality of the numbers displayed on the low-frequency signal generator's screen.
- Low calibration accuracy of the display screen of the low-frequency signal generator.
- Factors such as the removal of old display screens, which leads to cutting and sticking of digits (Wang et al., 2022).

Digital Electric Meter

- The display panel of the digital electric meter is typically 35mm high, 145mm wide, 108mm long, and has a character spacing of 6mm (Guan, 2018).
- Each individual digit has a uniform width of 12mm, a height of 24mm, and an aspect ratio of 2:1.
- The display screen generally consists of six digits; some models have five digits. The grayscale of the digits and the base plate is noticeably different compared to that of the panel and edges, making the texture features of the digits significantly visible after binarization.

The above information shows that the digital meter can serve as the basis for character segmentation. To achieve effective digit segmentation, the following points should be considered:

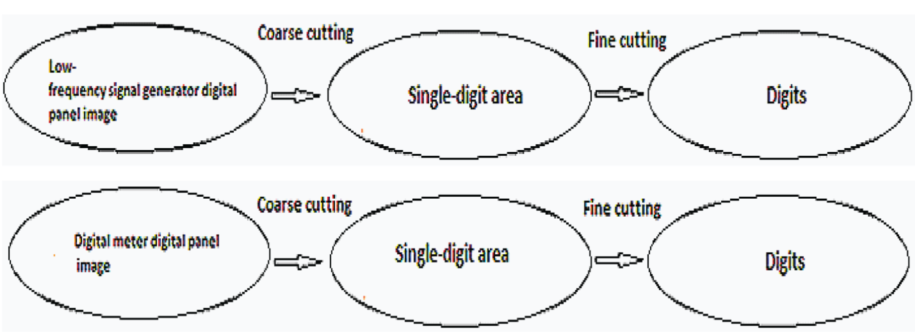
- Integrate the known information about the digital electric meter.
- Consider objective factors such as the display quality of the digits appearing on the digital electric meter.
- Remember that the digital meter has low display accuracy due to factors such as screen aging, breakage, and digit adhesion.

To explore effective solutions for relevant digital dial characters, the above points should be comprehensively considered and digit segmentation should be carried out based on objective criteria. The segmentation process is presented in Figure 3.

Fine Segmentation Algorithm for Numerical Characters

Based on the available information, a coarse segmentation algorithm for characters or digits is proposed that is based on binary wavelet 'scaling' of the image. Additionally, a binary threshold iteration method is suggested to deal with cases of character or digit adhesion or fragmentation. Consequently, the position of each character and digit can be determined, achieving an ideal and effective segmentation.

Figure 3. Fixed format instrument panel (low-frequency signal generator, digital instrumentation) sequential diagram for digit segmentation



The above concept is further elaborated as follows:

1. Correct the tilt of the fixed-format dial and obtain the characters displayed on the fixed-format dial. The digits are arranged horizontally, therefore, the displayed area on the fixed-format dial has a regular texture in the horizontal direction. The strokes and widths of characters and digits, the distances between them, and the stroke features affect the texture features.
2. In binarized images, the most prominent feature of texture is the background—pixels alternating between black and white among characters or numbers.
3. In the display panel of a fixed-format dial, there are 18 characters, 5 numbers, etc. For different dials, the quantity of displayed characters and numbers varies.
4. For example, if the display panel shows five or 18 digits, the alternating frequency of black-and-white pixels is at least five or 18, and the number of continuously segmented rows of target pixels in the binary image is calculated to be greater than five or 18.
5. Select the starting point of the region with the maximum number of continuous rows, i.e., the upper and lower boundaries of characters and digits, to accurately position the upper and lower edges of characters and digits. This step eliminates the impact of characters, digits, and other foreign objects that do not need to be read in the fixed-format dial display panel (Wang et al., 2022).

A basic ideal black-and-white pixel image is obtained after binarization according to the above method, followed by the segmentation step. Therefore, selection of the candidate segmentation points is an important step in character and digit segmentation. Currently, the most commonly used segmentation method is the vertical projection method, which is used to determine the cutting points for characters and digits. It is described as follows:

1. Vertically scan each column of the image.
2. Count the number of target pixels in each column.
3. Arrange the display in order from bottom to top.

Let an x×y image f be represented as follows:

$$R\left(q\right)=\sum_{p=1}^{x}f\left(p,q\right) \tag{20}$$

If there is no noise or interference between characters or digits in a binary image, the left and right boundaries of each character or digit can be directly determined based on their vertical projection. However, in reality, due to adverse working conditions such as lighting, and limited cleanliness of the display, characters and digits, different interference-causing factors can lead to adhesion between characters, digits, borders and digits. Therefore, using only the aforementioned vertical projection method for segmentation would result in segmentation errors (Zhou et al., 2022).

Hence, a segmentation point selection method based on multiscale wavelet analysis is proposed that utilizes the 'scaling' functionality of wavelets. The method is as follows:

1. Histogram projection points are represented from coarse to fine, providing a finite number of slots (candidate segmentation points) at the optimal scale.
2. The width-to-length ratio characteristics of characters and digits are combined to locate boundary segmentation points.

Consider the following one-dimensional discrete wavelet function expression:

$$\psi_{q,e}\left(h\right)=2^{-q/2}\,\psi\left(2^{-q}h\right)q\in 0 \tag{21}$$

The expression for the discrete wavelet transform is:

$$M_{2^q}f\left(m\right)=\frac{1}{2}\int_{-\infty}^{\infty}f\left(h\right)\psi\left[\frac{m-h}{2^q}\right]dh,q\in 0 \tag{22}$$

Equation (22) represents automatic scaling that is a feature of the wavelet transform, which allows analysis of signal characteristics based on the value of the scale q. Significant signal changes are observed when the scale is large. When the scale is small, the observed changes are minor (Yang et al., 2022).

Substituting the vertical projection value R(q) into (22), we get:

$$M_{2^e}R\left(q\right)=\frac{1}{2}\int_{-\infty}^{\infty}J\left(h\right)\psi\left[\frac{q-h}{2^e}\right]dh,e\epsilon 0 \tag{23}$$

The use of Mallat wavelets enables implementation of fast algorithms.

The above-mentioned steps aim to enhance the accuracy and effectiveness of image segmentation by utilizing finite-level wavelet transforms on limited samples for vertical projection points, employing algorithms that favor odd and even symmetric wavelets in the selection of candidate segmentation points and ensuring correspondence between trough points in vertical projection and feature points in wavelet transforms: Here are the next steps:

1. A vertical projection point consists of a finite number of samples, requiring a finite-level wavelet transform.
2. Odd-symmetric and even-symmetric wavelets should be chosen for selecting the candidate segmentation points.
3. It should be ensured that the notch points in the vertical projection correspond to the characteristic points of the wavelet transform.

We choose the sym2 wavelet to perform the following steps:

1. Two-scale one-dimensional wavelet decomposition, performed on the vertical projection image; and
2. Signal low-frequency reconstruction of the wavelet system.

Following the above steps, the signal undergoes wavelet transformation, preserving the main information of the signal while simultaneously eliminating a significant amount of redundant information that could affect computational speed.

Then, proceed with the following steps:

1. Determine the candidate small valley points. In the context of image segmentation research, candidate valley points typically refer to positions or specific features in the image that could potentially serve as segmentation boundaries. These points may be crucial for delineating boundaries between different regions or objects in the image. Determining candidate valley

points may involve various image processing and analysis techniques to locate positions that potentially signify region divisions in the image.
2. Synthesize the aspect ratio feature of characters (Jin et al., 2022).
3. Set the threshold as half the height of characters and digits in order to determine the segmentation point for the fixed-format dial.

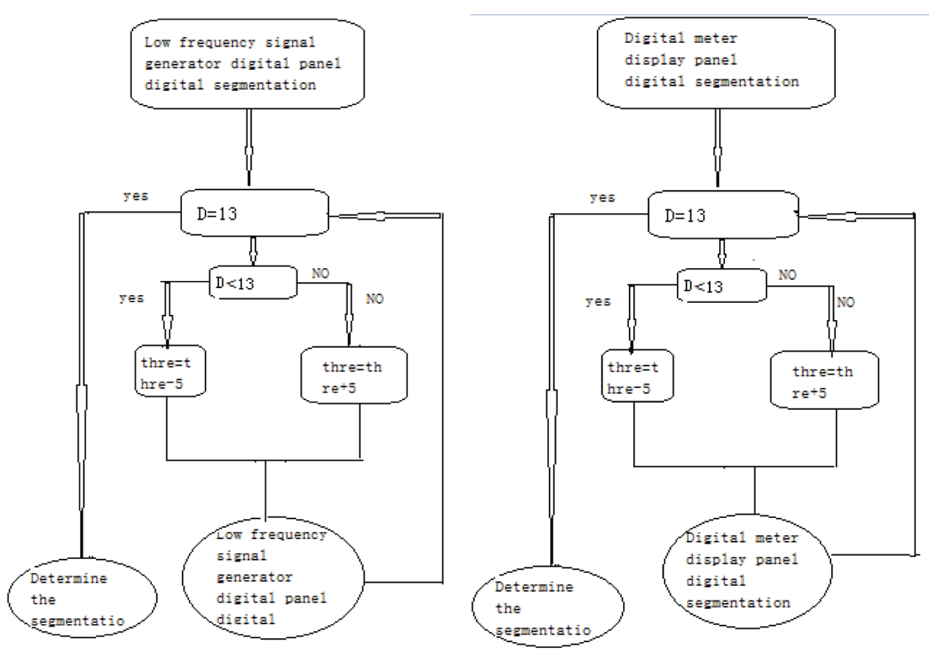
Next, we provide an example of the dial of a low-frequency signal generator to illustrate the specific segmentation process.

The dial of the low-frequency signal generator has twelve numbers, so the correct segmentation point should be thirteen. However, in actual segmentation, if the working environment of the low-frequency signal generator experiences prolonged interference or harsh conditions, it may lead to a lack of distinct grayscale features in the background, directly causing the segmentation point not necessarily to be 13. We choose to apply an iterative method, using the difference between the number of segmented regions and the number of characters after wavelet vertical projection as a reference factor. The iterative selection is carried out to find the binarization threshold that meets the requirements when dealing with the image of the low-frequency signal generator. The purpose of the iteration is to identify the optimal binarization threshold for improved image segmentation. Throughout this process, various thresholds are tested iteratively and, based on certain criteria (possibly differences in the number of segmented regions and characters), the most suitable threshold is chosen to ensure the desired segmentation outcome. The iterative process is illustrated in Figure 4.

From the above figures, it can be observed that:

- If the segmentation point D < 13, then decrease the binarization threshold 'thre' in increments of 5.
- If the segmentation point D > 13, then increase the binarization threshold 'thre' in increments of 5 until the segmentation point is 13.

Figure 4. Binarized threshold iteration sequence diagram (low-frequency signal generator, digital ammeter diagram)



The actual experimental results are as follows, showing very good performance. The binarization iteration effect is shown in Figure 5.

As shown in (a1) and (a2) in Figure 5, severe 'number' adhesion can be observed, leading to the mis-segmentation of the upper and lower boundaries of the 'number' region. Therefore, the segmentation point must be greater than 13 (in reality, the segmentation point reaches 24 in this case).

The following methods are employed to eliminate the number adhesion error:

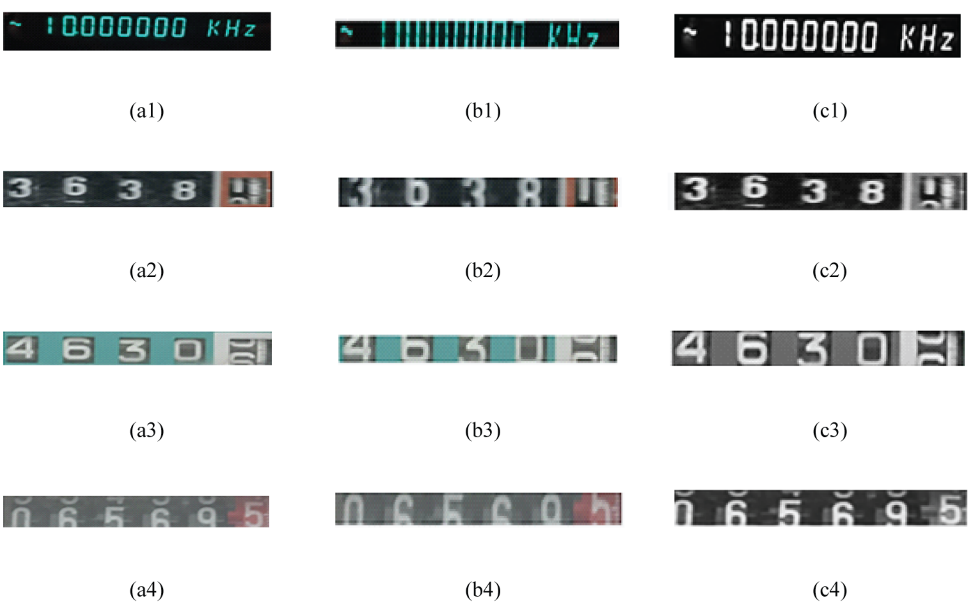
1. It is observed that the use of binarized iteration makes it easier to find the segmentation point after eliminating the number adhesion phenomenon.
2. Due to variations in binarization thresholds, individual distortions may occur in 'numbers.' After segmentation, the stroke width of 'numbers' is used in a search to determine whether to choose a larger or smaller binarization threshold. Alternatively, the original image can be binarized using the original threshold (Li et al., 2021).

The above is the coarse segmentation algorithm for numbers on the dial panel that follows a fixed format. The same approach is used for coarse segmentation of characters on the fixed format dial panel.

Concept of Numeric and Character Fine Segmentation Algorithm

A method for fine segmentation of numbers and characters using edge-based recognition of numbers and characters is proposed as follows:

Figure 5. Binary iterative renderings (renderings required for panel drawings of the low-frequency signal generator and digital electric meter)



Note. (a1) Binary graph; (b1) Wrong extraction of character area; (c1) Binarized iterative graph; (a2) Binary graph; (b2) Wrong extraction of character area; (c2) Binarized iterative graph; (a3) Binary graph; (b3) Wrong extraction of character area; (c3) Binarized iterative graph; (a4) Binary graph; (b4) Wrong extraction of character area; (c4) Binarized iterative binarization graph.

1. Binarily represent numbers and characters using different thresholds.
2. Arrange the above sub-images (the small images or sub-images obtained in the first step by binarizing numbers and characters using different thresholds) into one image based on rows and columns.
3. Combine known information about the fixed format dial to perform wavelet filtering on the vertical and horizontal projections of the entire image. The result is used to identify segmentation points.

After performing the above operations, if there are individual sub-images that experience fragmentation or adhesion due to binarization effects, it may not be possible to achieve complete segmentation for the entire image (Li, 2021).

Below, we describe the multi-line vertical projection method. The purpose of exploring the multiple-line vertical projection method in image segmentation research is typically for detecting and segmenting text lines or characters. This method involves projecting lines vertically onto the image, analyzing pixel density variations along these projection lines to identify the positions of text lines or characters. It aids in recognizing and extracting textual information from images, commonly used in applications such as Optical Character Recognition (OCR).

Vertical projection is performed on a multi-line text image and positions with zero projection values are searched. The resulting positions form the cutting points of the text image.

In the context of an image with dimensions x \times yx×y, the image ue(p,q)(e=1,……r)ue(p,q)(e=1,……r) is represented as follows:

$$R\left(q\right) = \sum_{e=1}^{r}\sum_{p=1}^{x} U_e\left(p,q\right) \quad (24)$$

We know from the above discussion that any single-line text image may experience fragmentation or adhesion, but the segmentation of multi-line images will not be affected.

The specific operational process is as follows:

1. Apply different binarization thresholds to the number and character images, resulting in Y binarized images.
2. Arrange the binarized images in row and column order, which are described by the following equations:

Row arrangement:

R(q)> e 1 (25)

Column arrangement:

$$R\left(p\right) = \sum_{e=1}^{r}\sum_{q=1}^{y} U_e\left(p,q\right) > e2 \quad (26)$$

3. Perform vertical and horizontal projections on the arranged images.

4. As previously explained, the ongoing wavelet filtering is applied to multi-line projection points. When searching for the wave troughs, it is necessary for them to exceed a certain threshold, denoted as e. The threshold e is adaptively adjusted based on the proportional characteristics of digits and characters.
5. Establish the upper and lower boundaries of digits and characters, with the positions already determined. Additionally, the aspect ratio of characters and digits is typically 2:1, with a difference generally not exceeding 3 pixels.
6. If the requirements of (5) cannot be met, then verify the presence of conditions such as noise, discontinuity, adhesion, etc., at the cutting positions.
7. The threshold is adaptively adjusted using a step size of one to meet the desired requirements (Yang & Ren, 2021).

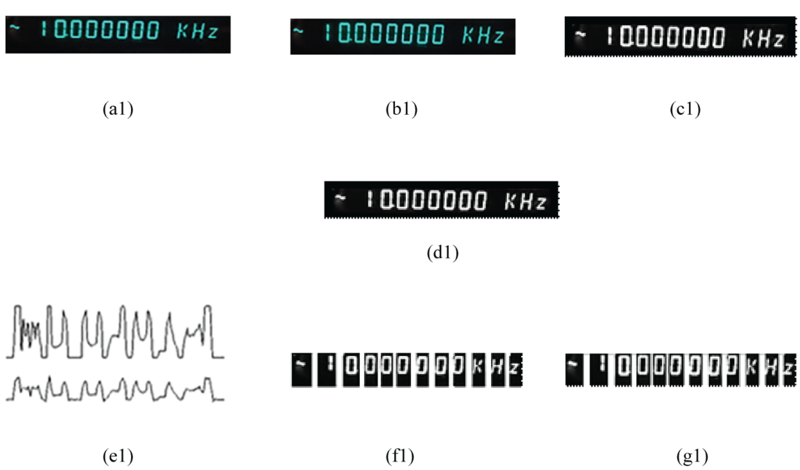
Analyze the Envisioned Effectiveness and Practicality With Real Examples

The fixed proportional relationship of numbers displayed by the low-frequency signal generator is considered to illustrate the process of extracting individual digits.

Using the Hough transform and wavelet analysis, a series of steps is taken to remove interference in the complex background. Individual characters and numbers are extracted after determining the boundaries of characters and numbers. The specific steps are as follows:

1. Apply an improved Hough transform for skew correction to the number image from the low-frequency signal generator shown in Figure 6 (a1). The result is shown in Figure 6 (b1).
2. Perform binarization to obtain a binary image as shown in Figure 6 (c1).
3. Determine the upper and lower boundaries of the number based on the characteristics of its texture. An image of the number is obtained from the area between the boundaries and is shown in Figure 6 (d1).
4. Conduct two-scale one-dimensional wavelet decomposition for the vertical projection image. The result is shown in Figure 6 (e1).

Figure 6. Digital segmentation steps for the dial numbers of a low frequency signal generator



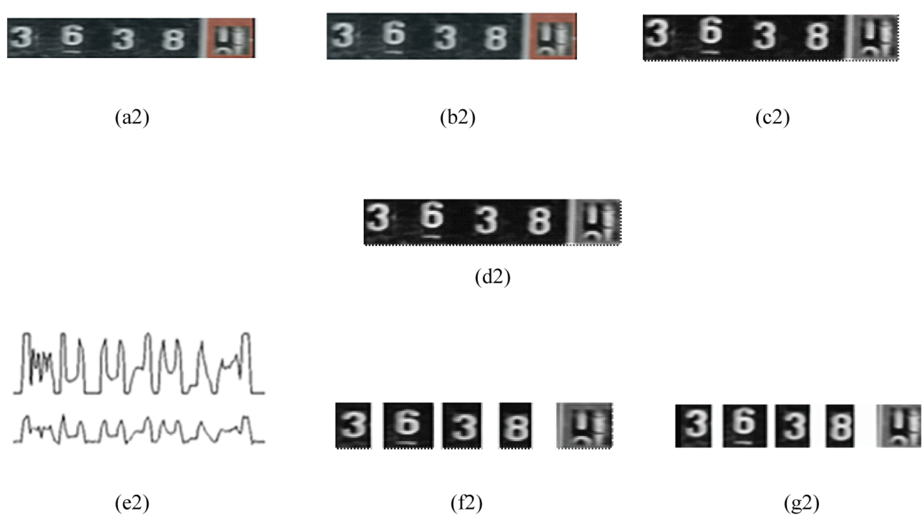
(a1) Original image; (b1) Complete corrected image; (c1) Binary image; (d1) Numeric character range; (e1) Vertical projection and wavelet filtering; (f1) Roughly segmented image; (g1) Finely segmented image.

5. Reconstruct the low-frequency signals from the wavelet coefficients. Subsequently, use a binary threshold iteration method to perform coarse segmentation of individual numbers in Figure 6 (d1), as shown in Figure 6 (f1).
6. Conduct wavelet filtering and perform projection on the multi-line vertical projection image. Subsequently, select cutting points precisely to perform fine segmentation on the number area, where independent numbers are extracted using upper and lower boundaries. The extracted numbers are standardized to the specified image size and demonstrated in Figure 6 (g1) (Yang et al., 2021).

Next, we utilize the fixed proportional relationship of numbers displayed by the digital electric meter to further explain the segmentation process of a single digit. The Hough transform and wavelet analysis are utilized to remove interference in the complex background. Individual characters and numbers are extracted after determining the boundaries of characters and numbers. The specific steps are as follows:

1. Apply an improved Hough transform for skew correction of the number image obtained from the digital electric meter. The numbers before and after skew correction are shown in Figures 7 (a2) and 7 (b2), respectively.
2. Perform binarization to obtain a binary image, which is demonstrated in Figure 7 (c2).
3. Based on the characteristics of the number's texture, determine the upper and lower boundaries of the number. An image of the number area is obtained as shown in Figure 7 (d2).
4. Perform two-scale one-dimensional wavelet decomposition on the vertical projection image. Figure 7 (e2) shows the result.
5. Reconstruct the low-frequency signals from the wavelet coefficients. Subsequently, use a binary threshold iteration method to perform coarse fragmentation on Figure 7 (d2) to extract individual numbers, as shown in Figure 7 (f2).

Figure 7. Digital segmentation steps of numbers displayed on a digital electricity meter



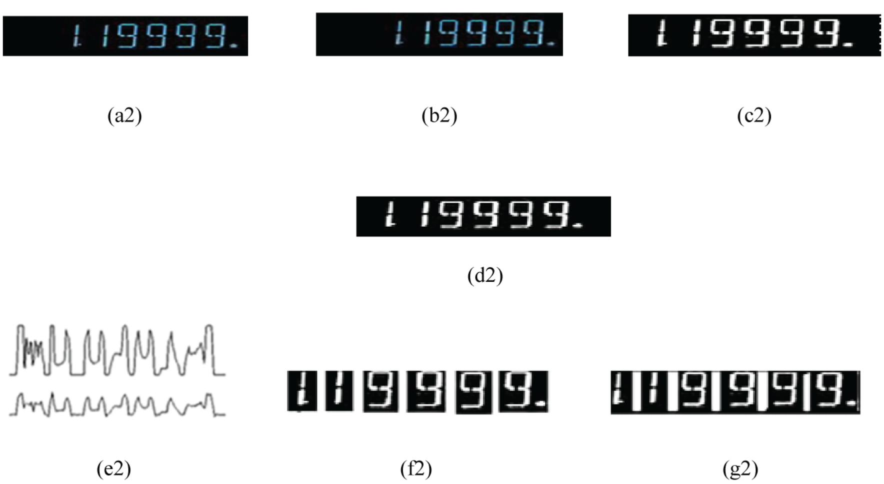
Note. (a2) Original image; (b2) Complete corrected image; (c2) Binary image; (d2) Numerical character range; (e2) Vertical projection and wavelet filtering; (f2) Roughly segmented image; (g2) Finely segmented image.

6. Perform wavelet filtering and projection on the multi-line vertical projection image (Chang et al., 2021). Subsequently, select precise cutting points to perform fine segmentation on the number area, extracting independent numbers using upper and lower boundaries. The extracted result is standardized to the specified image size and shown in Figure 7 (g2).

In the following, we display the fixed proportional relationship between the numbers using a digital multimeter to further explain the process of fragmenting individual numbers. The process involves the Hough transform and wavelet analysis to remove interference from complex backgrounds. Individual characters and numbers are extracted after determining the boundaries of characters and numbers. The specific steps are as follows:

1. The digital image shown in Figure 8 (a3) is obtained using a low-frequency signal generator. It is corrected for skew using an improved Hough transform and the corrected image is displayed in Figure 8 (b3).
2. Binarization is performed to obtain a binary image shown in Figure 8 (c3).
3. The upper and lower boundaries of the numbers are determined based on the characteristics of the number texture. Figure 8 (d3) shows the image corresponding to the extracted numbers.
4. Two-scale one-dimensional wavelet decomposition is performed on the vertical projection graph. The result is shown in Figure 8 (e3).
5. The wavelet coefficients corresponding to low-frequency signal are calculated and subsequently the binary threshold iteration method is used to perform coarse fragmentation on Figure 8 (d3) to extract individual numbers, which are shown in Figure 8 (f3).
6. Perform wavelet filtering and project the multi-line vertical projection graph using wavelets (Wang et al., 2021). Subsequently, accurate cutting points are selected to finely cut the number area and extract independent numbers using the upper and lower boundaries. The extracted numbers are normalize to the specified image size and shown in Figure 8 (g3).

Figure 8. Digital segmentation steps of numbers displayed on digital multimeter display



Note. (a2) Original image; (b2) Complete corrected image; (c2) Binary image; (d2) Numerical character range; (e2) Vertical projection and wavelet filtering; (f2) Roughly segmented image; (g2) Finely segmented image.

Comparison of Advantages, Disadvantages, and Applicable Scope of the Proposed Image Segmentation Method

We applied the segmentation method mentioned above to the instrument panel of a low-frequency signal generator, the dial of a digital multimeter, and the dashboard of an aircraft instrument. In terms of real-time performance, we observed average segmentation times of approximately 28ms, 26ms and 24ms for images from the low-frequency signal generator, digital multimeter instrument panel, and aircraft instrument panel, respectively. The specific segmentation time for each instrument panel image is subject to various factors, including image complexity, resolution, lighting conditions, and hardware performance. Based on our experimental results, the segmentation times provide a general range for the fuzzy time associated with each type of instrument panel image. In an image, fuzzy time typically refers to the unclear or uncertain temporal information associated with a specific indicator or object. This ambiguity may arise due to factors such as image quality, photographic conditions, or other elements that introduce a blurry effect, making it challenging to accurately determine the timestamp or time range of the specified object.

We conducted a comprehensive assessment of the memory utilization associated with the proposed segmentation method. This evaluation involves analyzing the memory utilization footprint during the execution of the segmentation process for the images obtained from low-frequency signal generator dial, digital multimeter instrument panel, and aircraft instrument panel. The results indicate that the proposed method maintains reasonable memory efficiency across various scenarios. Additionally, we discussed the applicability of the segmentation method to real-time applications by assessing its compatibility with respect to the computational and memory requirements imposed by real-time processing constraints. The findings suggest that the proposed method satisfies these constraints, making it suitable for deployment in applications that require real-time responsiveness (Ankora & Aju, 2022).

Next, we determined the limitations of the proposed segmentation method. We used the digital multimeter to identify certain limitations associated with the proposed segmentation method. Addressing these limitations is crucial as they impact the method's performance in specific scenarios. These limitations encompass challenges in handling highly complex or textured images, potential sensitivity to variations in lighting conditions, and the necessity for further optimization when dealing with large datasets.

We also suggest different measures for improving the accuracy and robustness of the segmentation method in future. The accuracy and robustness of the segmentation method can be improved by exploring advanced machine learning techniques, such as deep neural networks, to adaptively learn and adapt to diverse image characteristics. Additionally, more comprehensive datasets that consider a wide range of environmental conditions and instrument panel variations can be used, as these datasets can contribute to a more robust and versatile segmentation model. Continuous refinement and validation against challenging scenarios will be instrumental in advancing the proposed method's effectiveness.

In the future, we will focus on investigating factors that may be encountered in practical applications, such as low-resolution images, impact of noise, and background obstruction. We will explore and analyze the implications of these factors on the effectiveness of digit and character segmentation technology, with the aim to establish a comprehensive understanding of the authenticity and applicability of the research results. (Li et al., 2022).

The following are a few indicators to illustrate:

- Precision: Precision refers to the proportion of samples correctly predicted as the positive class out of all samples predicted as the positive class. It is calculated as follows:
    - True Positives: This refers to the number of pixels that the model successfully and accurately predicts as belonging to the positive class. This includes the correct classification of pixels belonging to the target object, resulting in an accurate segmentation outcome.
    - True Positives is approximately 0.94.

- Recall: Recall is the proportion of samples that are correctly predicted as the positive class out of the actual positive samples. It is calculated as:

\text{Recall} = \frac{\text{True Positives}}{\text{True Positives + False Negatives}}Recall=
True Positives + False
Recall is approximately 0.95
F1 Score: Negatives
True Positives

The F1 Score is the harmonic mean of precision and recall, providing a comprehensive assessment of the model's accuracy and coverage. The expression for calculating the F1 Score is as follows:

\text{F1 Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision + Recall}}
F1 Score=2×Precision + Recall
Precision×Recall
F1 Score is approximately 0.94

These metrics will enable a comprehensive evaluation of the segmentation method's performance in recognizing characters and numbers, offering a clear understanding of the model's overall performance from different aspects.

In the following, we describe some advantages of threshold segmentation methods compared to other advanced segmentation techniques:

- **Simplicity and ease of use:** Threshold segmentation is an intuitive and easy-to-understand method that does not involve complex parameter tuning, making it suitable for straightforward image segmentation tasks.
- **Computational efficiency:** Due to its simple implementation, threshold segmentation typically exhibits fast computational speed, making it suitable for real-time applications or scenarios with low computational resource requirements.
- **Intuitiveness:** The results of threshold segmentation can be visualized by setting an appropriate threshold, facilitating user understanding and feedback.
- **Wide applicability:** Threshold segmentation can achieve satisfactory results in certain scenarios, especially those with high contrast and distinct foreground and background.

Threshold segmentation also has some limitations, particularly in handling complex scenes, images with significant grayscale variations, or tasks requiring high-precision segmentation. In such scenarios, advanced methods like deep learning-based semantic segmentation may be more suitable. These methods can learn high-level features from images, adapt to different scenarios, and provide accurate segmentation results in more challenging situations. However, deep learning segmentation methods have certain drawbacks compared to threshold segmentation methods, which are as follows:

- **Complexity:** Deep learning segmentation methods typically require intricate network architectures and a large number of parameters for training, which increase their implementation complexity and reduce their interpretability.
- **Computational complexity:** Training deep learning models often requires significant computational resources and time, making it challenging to apply these methods in environments with limited computational resources.
- **Data requirements:** Deep learning methods usually necessitate a substantial amount of well-labeled training data, which may not always be easy to obtain or may involve high acquisition costs.

- **Adversarial nature:** Deep learning models may exhibit adversarial behavior in the face of specific input variations, resulting in unstable performance in practical applications. Adversarial behavior" in the context of deep learning refers to situations where the model reacts unexpectedly or exhibits undesirable outcomes when faced with specific input variations. This can include instances where subtle, carefully crafted changes to input data lead to significant and potentially harmful misclassifications or errors in the model's predictions. Adversarial behavior is a concern as it can impact the reliability and stability of deep learning models in real-world applications.
- **Black-box nature:** Deep learning models are often considered black boxes, making it challenging to explain their internal workings. This may be undesirable in scenarios where it is crucial to have a high level of model interpretability.

Although deep learning segmentation methods excel in handling complex scenes and improving segmentation accuracy, their drawbacks highlight situations where simpler methods like threshold segmentation may still hold certain advantages. The choice of an appropriate method often depends on the specific application requirements and available resources (Ankora & Aju, 2022).

When threshold segmentation is carried out on input images that are affected by noise, distortion, and contamination, one can use filtering techniques to mitigate the impact of noise, employ image enhancement methods to reduce distortion, or explore preprocessing steps to enhance the robustness of segmentation (Sukte et al., 2022).

When the binary threshold segmentation method is used for image segmentation in real-world applications, factors such as lighting conditions, camera noise, and dirt or scratches on the instrument panel may affect the quality of the input images. To address these issues, different techniques can be implemented, such as illumination correction for handling lighting variations, image denoising methods to reduce camera noise, and image cleaning and restoration techniques to address dirt or scratches on the dashboard. The use of these techniques can help enhance the algorithm's adaptability to complex real-world environments (Gao, 2021).

Despite the advantages of threshold segmentation methods, such as simplicity and high computational efficiency, their performance may be suboptimal in case of complex scenes, significant changes in lighting, or poor image quality, making them susceptible to noise and distortion. Therefore, in practical applications, there is a need to balance their simplicity and applicability, considering the potential addition of preprocessing steps to enhance segmentation robustness (Yan & Zhong, 2017).

In the aforementioned complex scenarios, the use of deep learning methods might be a useful option. However, it is crucial to note that these methods have high technical requirements and can be relatively time-consuming. Balancing the technical prerequisites and time costs is a key criterion for choosing a segmentation method suitable for a specific scenario (Chen et al., 2020).

CONCLUSION

The Hough transform was utilized for inclined correction of fixed-format dial images. Furthermore, the binary wavelets are applied for "zoom-in," considering their advantage of not disrupting the signal under time-shift invariant conditions.

Based on the "zoom-in" images obtained after the use of binary wavelets, a coarse segmentation algorithm for characters or numbers was implemented, proposing an iterative binary thresholding method to deal with character or number adhesion, or fragmentation. This helped determine the area corresponding to each character or number, achieving an ideal and efficient segmentation.

A refined method was proposed for segmenting numbers and characters along the boundaries, based on the premise that digit and character segmentation was an application of computer video image recognition technology for specific instrument panel digit and character recognition. It could extract moving digit and character images from complex backgrounds, segment them, and achieve precise recognition. This paper focused on precise segmentation of digits and characters, utilizing a unique approach to segment digits and characters in the fixed-format dial. An image could still be segmented effectively even if it experienced severe distortion. Experimental results showed that this method achieved a recognition rate of 98.5% for letters and numbers, proving its effectiveness and practical value. This study's findings can be applied in disciplines and fields such as measurement and control, mining, archaeology, early warning systems, and defense. It can serve as an effective technological tool both now and in the future, playing a crucial role across various industries, with broad applications and profound impact. The development of computer science, image recognition, artificial intelligence, and other disciplines, has placed the study of specific target recognition in complex environments at the forefront of current technological development, holding great significance in fields such as health, mining, defense, and military.

Although significant progress has been achieved in digit and character segmentation technology, its practical applications still face certain challenges:

- Due to adverse weather conditions such as heavy fog, lighting, sandstorms, and so on, the collected images have low clarity. Consequently, digits and characters are affected by noise, causing the target images to be obscured by the background.
- Collected images consist of digits and text, and in some cases, contain characters from different languages. Due to the complex strokes of characters from some languages, binary processing can lead to blurred strokes, causing segmentation and recognition errors.

These two scenarios are frequently encountered in harsh conditions relating to defense, military, mining, and other areas, posing challenges to scientists in various countries.

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DATA AVAILABILITY

The data used to support the findings of this study are included within the article.

CONFLICTS OF INTEREST

The authors declare that there is no competing interest for this work.

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