Circuit Component Detection in Offline Hand-drawn Electrical/Electronic Circuit Diagram

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***Abstract*— Detection of circuit components from hand-drawn circuit image refers to the process of automatic separation of all the circuit components belonging to a circuit. In this work, we have devised an algorithm that accepts a hand-drawn circuit image as input and returns the circuit components marked with bounding box. We have proposed a method where we have used the morphological 'close' operator to create a structural dissimilarity between the circuit components and the wires. Then we have used run length smoothing algorithm (RLSA) based technique to remove all the wires. Finally, we have used the spatial coordinates of the circuit components in the wire-removed circuit diagram to localize them in the actual circuit diagram. The proposed methodology is evaluated over a database consisting of 60 circuit images collected from the copies of engineering students. Considering the complexity of the research topic, the result thus obtained is encouraging.**

Keywords*— *circuit component detection, electrical/electronic circuit, hand-drawn circuit, morphological operation, RLSA

I. Introduction

Circuit in layman terms is a closed path that allows electricity to flow from one node to another. This path consists of connecting wires which connect different electrical and/or electronic components. Circuit components can broadly be classified as electrical and electronic circuit components which allow uninterrupted flow of electricity or transfer of power through a circuit.

To understand and analyse real life circuits, circuit components are drawn following certain internationally accepted figures called circuit symbols. Each circuit component has its own unique symbol. The detection of such elements is, however, a cumbersome job but inevitable for circuit analysis. For circuits taken in bulk it becomes even more hectic. Here lies the need of automatic detection of circuit components. Digital image processing, the use of computer algorithms to process digital images, acts as a viable option for this automatic analysis of the circuit images.

In this context, it is noteworthy to mention that nowadays tools (like CircuitMaker, Computer-aided design (CAD), CircuitStudio) are available to draw circuit diagrams in online mode, most of which are commercially used. But, the common users prefer to draw circuit diagrams in hand rather than using such tools. Even, drawing a circuit using such tools take much time compared to drawing the same in hand. Therefore, no doubt it would be a wise decision to design a technique that can accept a hand-drawn circuit diagram and serve the same purpose like that of the said tool. This initiative would not only bypass the need of such tools by non-expert users but also save the time.

Circuit component detection using image processing refers to automated separation of circuit components from hand-drawn electrical/electronic circuits. This method acts as a more productive substitution for circuit analysis than its manual counterpart. These circuits can be collected in bulk using both online and offline means. An algorithm then takes hand-drawn circuits as input and localizes the circuit components present therein. Doing so, hand-drawn circuit diagrams, being difficult to be analyzed properly, can be converted into their printed counterpart that would be easier for visualization and storing purposes. This can also be very helpful in academic purposes, like for printing machine generated circuits directly from hand-drawn ones, reducing time and human labour.

However, the procedure is not as simple as it seems to be. The segmentation of such circuit components involves several challenges owing to the difference in shapes and sizes of the circuits as well as individual circuit components. Hand-drawn circuit diagrams enhance the difficulty level manifold by increasing the number of ways a single circuit component can be drawn unlike its printed counterparts. Challenges like varying paper quality, color and quality of ink used, writing pressure may not seem of much relevance at first glance but led to major misplays when solving this by means of digital image processing based algorithms.

II. Related Work

Though the complete work of segmentation of hand-drawn circuit images from document page initiated in 1990s [1], the topic received less attention from the researchers due to unstructured challenges; hence, the literature on the topic is inadequate. The complete scheme consists of various modules starting from image scanning, identifying the regions containing the components, removal of wires and finally, the localization of circuit components. Thus, a major part of this topic is an application in the field of digital image analysis.

In [2], the authors have suggested a method in which an image was pre-processed morphologically to obtain a thinned version of circuit image and then it was processed to localize the nodes and components. The nodes and components were segmented using pre-set thresholds on a spatially varying object pixel density. The connecting wires were then traced using a stack of pixels. In another work [3], authors have presented hierarchical object recognition based system for the said problem. It has relied on spatial tree structure representation and Bayesian framework of the circuit diagram. In this work the circuit components are built up from lower level image components (like circle, line), stored in a pre-created library. A probabilistic framework is used in order to get the circuit components from the tree structure special representation.

In another approach [4], the authors proposed a method in which morphological operations and geometric analysis were employed to recognize the circuit components. Three image spaces were created, namely H-, V-, and C- spaces, which respectively contained horizontal line segments, vertical line segments and the circuit symbols. These three spaces were built by morphological operations, which, in turn, were searched and scanned in a systematic way during the geometric analysis in order to obtain the recognized symbols by verifying the structural combination of their constituent primitives, thus separating the wires and circuit components.

Apart from morphology based methods, recent solutions involve the usage of chain codes [5], which is preferred by many researchers in effective segmentation of circuit components. In one such work [6], authors used chain codes to encode the boundary pixels of the circuit components and he connecting wires. Then the chains were divided into a set of graphical primitives (like circles, horizontal and vertical line segments) which were used to separate the circuit components and wires. Recently, in the work [7]on this field has been carried out where the authors segment the circuit component using a series of morphological operations on the binarized image. The binarized image is first classified into 3 categories namely closed shape, components with connected lines and disconnected components and then segmentation was carried out. This technique fails in identifying many components from the circuit diagram.

III. Proposed Work

Our aim here is to detect the circuit components from an image of hand-drawn circuit diagram. In order to achieve this, we have employed a deterministic technique in which the circuit diagrams are closed morphologically, followed by the removal of wires, and finally the localization of circuit components using rectangular bounding box is done. Entire work presented here has some key modules as shown in Fig. 1. We also describe these modules in the following subsections.

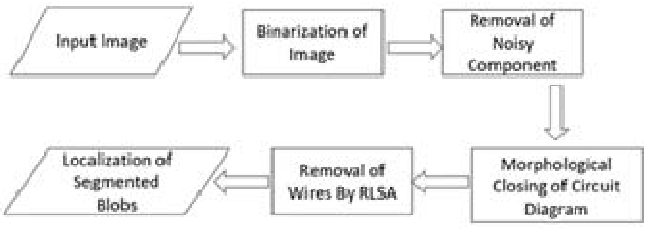


Fig. 1. Flowchart of the present circuit component detection technique from offline hand-drawn circuit diagram

A. Collection of hand-drawn circuit diagram

To evaluate any method, a realistic dataset is a pre-requisite. But to the best of our knowledge, there is no publicly available dataset of offline circuit diagrams to be used for our purpose. Hence, we have prepared an in-house dataset possibly by incorporating several circuit images drawn by different individuals.

The hand-drawn circuit diagrams for our work have been collected and scanned from the class notebooks and laboratory notebooks of several engineering students. The scanning has been done by an HP flatbed scanner with resolution of 300 dpi. Most of those circuit diagrams had been drawn in free-hand during class lectures and thus are very unsupervised in nature. Some of the collected sample circuit images are shown in Fig. 2(a-d).

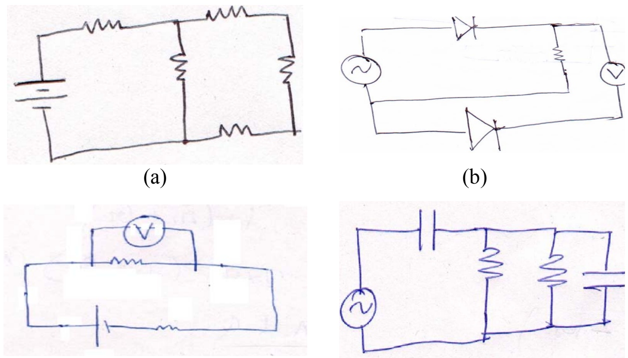


Fig. 2. Some samples of circuit diagrams taken from our dataset

B. Binarization of circuit images

Binarization in image processing is the technique by which any grayscale or colour image is converted into an image having only two levels of intensity namely - 0 (black) and 1 (white). In this work, we have binarized the images of circuit diagrams by a recently proposed method [8]. One example of binarized image is shown in Fig. 3.

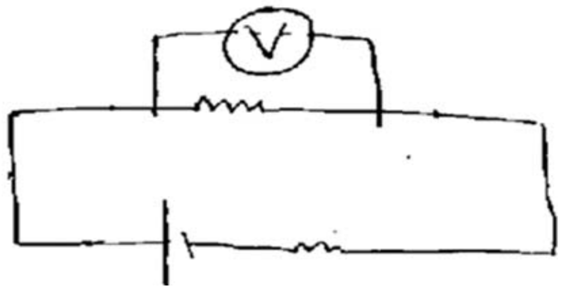


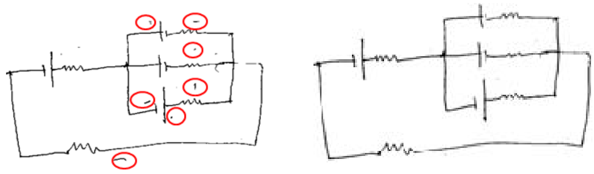
Fig. 3. Binarized image of Fig. 2(c)

C. Removal of noises

The hand-drawn circuit diagrams collected contain some inherent noisy elements due to some stray marks or dots put by the students who had drawn the diagrams while taking their class notes. Thus, it is necessary to remove those elements and in this module we have discussed a conventional method by which such noises could be removed efficiently. In this method, firstly, a connected component labelling (CCL) [9][10] technique is applied to identify each connected components in the circuit diagrams. Then the number of pixels contained in each connected component is determined. If that number is less than a pre-set threshold value (say, δ), then the connected component is treated as noise and is erased. Fig. 4 shows a noisy sample image and the corresponding de-noised version.

D. Blobbed circuit preparation

With the completion of the previous step, we have obtained a pre-processed version of the circuit diagram which is now ready for the localization process. The first step involved in the process of localization is the preparation of blobbed circuits. Here, by the term blobbed circuit, we refer to a circuit diagram in which the components have been thickened significantly with respect to the wires. As a result, all the components look like a ‘lump’ apart from the wires, which remain as it is. This process is very important in context of our work because after implementing this, a significant change is visible in the circuit diagram. In order to implement this, we have invoked the use of morphological ‘close’ operator [11][12]. We have intelligently chosen a disk structure element whose radius is sufficiently large so that most of the individual circuit components fit inside it. Then we have closed the noise removed binarized circuit diagram with the selected structure element. As a result, most of the circuit components are made to form a lump or blob, without much affecting the structure of the wires. Fig. 5 shows the effect of the implementation of this process on four such binarized circuit diagrams.



(a) A sample binarized circuit diagram with noisy component marked by cicular regions

(b) Circuit diagram after removal of noisy components

Fig. 4. Noisy sample image and its de-noised version

De-noised binarized circuit diagram

Blobbed circuit diagram

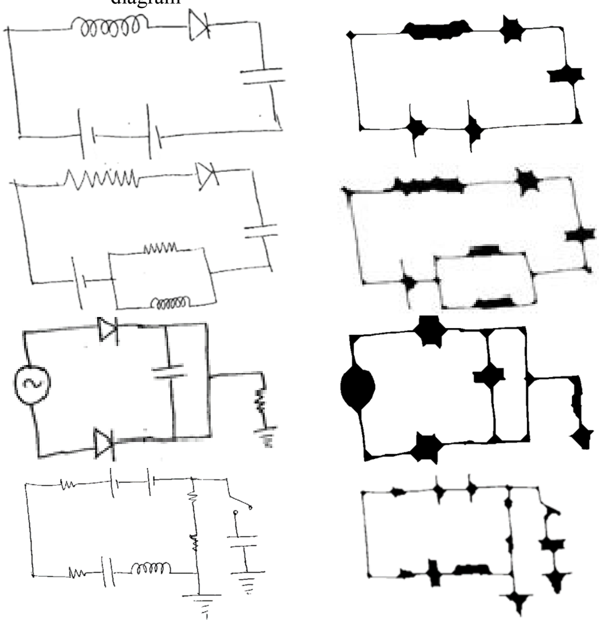


Fig. 5. Shows the de-noised binarized image (in left) and the corresponding transformed image which we call blobbed circuit

E. Extraction of blobbed circuit components

After the components take the shape of blob [13], we remove the wires efficiently from the diagram using the run length smoothing algorithm (RLSA) [14][15]. RLSA acts on binary images in a particular direction (usually horizontal or vertical) by substituting a sequence of background pixels with foreground pixels if the number of background pixels in the sequence is less than or equal to a predefined threshold value ‘C’. The algorithm transforms a binary sequence x into an output sequence y according to the following rules:

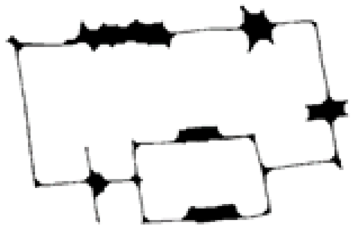
1. 1’s (white pixels) in x are changed to 0’s (black pixels) in y if the number of adjacent 1’s is less than or equal to a predefined threshold ‘C’.
2. 0’s in x remain unchanged in y.

For example, with C = 5 the sequence x is mapped into y as follows:

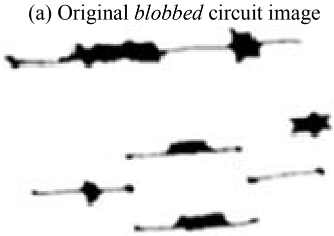
x : 1110111111010111101111111100111

y : 0000111111000000001111111100000

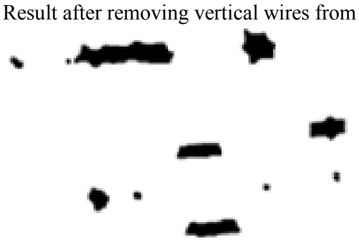
In contrast to this, in our work, we have employed this algorithm for transforming foreground pixels into background ones (i.e., ‘0’s into ‘1’s). We have applied this algorithm in both horizontal and vertical directions. This algorithm helps us in detecting the wires by identifying the rows/columns having lesser number of foreground pixels than a predefined threshold value ‘C’ and it consequently removes the wires by changing those foreground pixels to background pixels. Initially, we have applied the RLSA on the blobbed circuit diagrams in the horizontal direction and as a result, the vertical wires are removed as demonstrated in the Fig. 6 (b). Next, we remove the horizontal wires and for which we have again employed the RLSA on the vertical wire removed image in the vertical direction. So the remaining horizontal wires are removed leaving behind some isolated blobs as shown in Fig. 6 (c).



(a) Original *blobbed* circuit image



(b) Result after removing vertical wires from (a)



(c) Result after removing horizontal wires from (b)

Fig. 6. Depicts the output after applying RLSA based wire removal method

ISBN: 978-1-7281-4283-8

PART NO.: CFP20O01-ART

F. Localization of segmented components

In this stage, we have again applied CCL algorithm to identify each of the blobs separately from wire removed image. Then we have determined the following two parameters of the blobs using the connected components.

- Coordinate of the upper left corner of a blob.
- Coordinate of the bottom right corner of a blob.

These two parameters of a blob help us to determine the exact location of blob in the original circuit image. Thus we have used these locations to put bounding boxes around the blobs, and consequently around the circuit components in the original image. An image with localized circuits components is shown in Fig. 7.

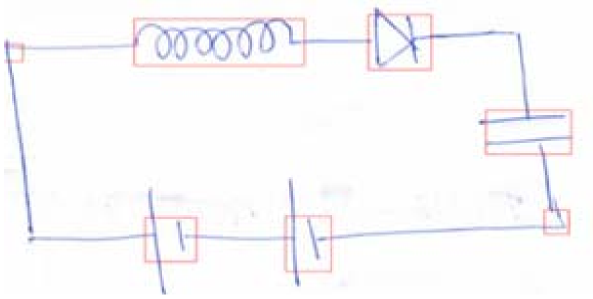


Fig. 7. Shows image after detecting the circuit components. The circuit components are shown in rectangular bounding box.

IV. RESULT AND ANALYSIS

As already mentioned, in the present work, we have designed a method for detecting circuit components from the hand-drawn circuit diagrams. For evaluation of our proposed method, we have collected 60 hand-drawn circuit diagrams in total from the notebooks/assignment sheets of engineering students. These 60 hand-drawn circuit diagrams contain 172 circuit components in total.

We determine the percentage of localization accuracy of our method by the following formula [16]:

Localization accuracy (in %) = (number of localized components)/(total number of actual components) ×100%

Out of these 172 circuit components, present technique localizes 157 components correctly. Therefore, the localization accuracy of the present circuit component detection technique is 157/172×100%=91.28%. In our work, we have considered about 14 types of circuit elements as distinct classes. We have manually calculated the localization accuracy of individual classes in the circuit diagrams using the same formula mentioned above. Class wise detection results are listed in Table 1.

A. Error case analysis

Though our proposed model has shown impressive results for detecting most of the circuit components but it fails to detect 8.72% (i.e. 15) components. Additionally, in few cases the present technique has ended up in detecting circuit components wrongly. Such failures occurred mostly due to following reasons.

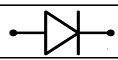
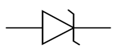
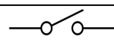
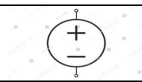
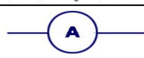
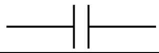
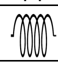
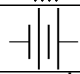
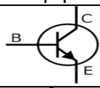
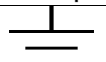
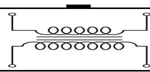
1) Oversized circuit components

It is to be noted that all the circuit diagrams under consideration are made without any restriction on the size of each component drawn by the individuals. In cases when a component (mainly capacitor and battery) is drawn by the students with large gap (see Fig. 8 (a)) the selected mask (mentioned in section III.D) fails to form a blob of that component.

2) Closely drawn components

Sometime two components are drawn very close to each other (see Fig. 8(b)) and the mask, considered here, connects both the components to form a blob together. This case is true for multiple components spaced very closely. Because of the components forming a blob together, the bounding box is formed around the components as a whole, resulting in incorrect identification.

TABLE I. RESULTS OF DETECTION OF CIRCUIT COMPONENTS USING OUR PROPOSED METHOD. THE COMPONENT WISE RESULTS ARE VISUALLY CALCULATED FROM THE FINAL OUTPUT OF DETECTED COMPONENTS IN THE CIRCUIT DIAGRAM. THIS IS DONE FOR BETTER UNDERSTANDING OF DIVERSITY OF CIRCUIT COMPONENTS USED AND WHEN WE MEET WORST ACCURACY IN THE PRESENT DETECTION ALGORITHM.

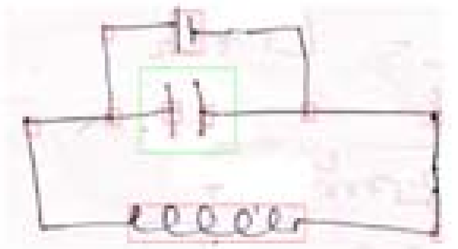
Class	**Symbolic representation**	**Actual count**	**Correctly localized**	**Accuracy**
PN Junction Diode		10	9	90%
Zener Diode		7	7	100%
Switch		2	2	100%
AC Voltage Source		5	5	100%
DC Voltage Source		4	4	100%
Ammeter		7	6	86%
Voltmeter		6	6	100%
Resistor		53	49	92%
Capacitor		20	18	90%
Inductor		10	9	90%
Battery		25	22	88%
Bipolar Junction Transistor		10	8	80%
Ground		11	10	91%
Transformer		2	2	100%

3) Error at nodal points and corners

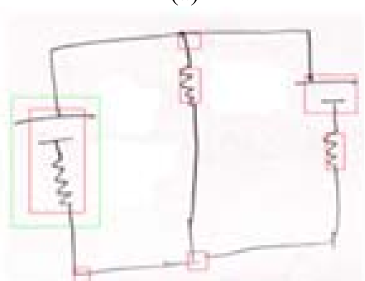
A nodal point in a circuit is the point of intersection of three or more current paths (wires). In such areas, because of the relative position of the wires with respect to each other, our chosen mask used in 'close' operator forms a blob at these points. Similar is the case for corners in the circuit diagrams. Thus they result in localization of unwanted circuit components, namely the nodes and corners. Such cases are shown in Fig. 8(c).

V. CONCLUSION

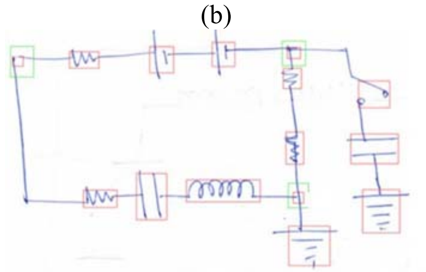
Our proposed algorithm based on morphological operations and RLSA successfully detects the circuit components in the electrical and electronics circuit diagrams. It efficiently tackles variations in drawing styles as well as takes care of the stray marks put unintentionally in the circuit diagrams. The efficiency of our algorithm is endorsed by testing on several circuit images available in our self-created database. Few cases where our method fails to deliver accurate results include extremely oversized circuit components (mainly capacitor and batteries) and very closely spaced circuit components. The output of this circuit component detection method can be fed to recognition module so that each component would be identified properly. This would complete the actual purpose of the hand-drawn circuit image analysis by the usage of digital image processing. In addition, the present would be beneficial for other circuit analysis applications, mainly in converting hand-drawn circuit diagrams into their printed versions for easy understanding and study, and for various commercial / non-commercial uses. Commercial manufacturing of circuit diagrams would become much cost-effective and thereby resource efficient if the hand-drawn circuits on paper medium can directly be converted to machine printed ones instead of drawing them using available tools.



(a)



(b)



(c)

Fig. 8. Some cases of error in our proposed method. Bounding box of the erroneous components are shown within green colored rectangle

ACKNOWLEDGEMENT

We would like to thank CMATER research laboratory of the Computer Science and Engineering Department, Jadavpur University, India for providing us the infrastructural support. This work is partially supported by the PURSE-II and UPE-II, Jadavpur University projects. Ram Sarkar is thankful to DST, Govt. of India, for the grant (EMR/2016/007213) to carry out this research.

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