Cost-efficient universal Approach for Remote Meter Reading Using Web Services and Computer Vision

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Abstract—The Internet of Things is a great vision but also an important challenge for the current research. Through, the connection of many different devices there are outstanding benefits such as an increasing automation and intelligent energy management. Nevertheless, the integration of legacy devices into the Internet of Things is a significant issue. Legacy meters, e.g., cannot provide metering data automatically and the installation of modern smart meters is cost-intensive and thus often unprofitable. An alternative approach is to extend legacy meters with an automatic meter reading system. Thus, they can be integrated into an intelligent system such as an efficient energy management. In this paper a robust and universal approach for automatic meter reading is proposed. The approach can be applied to water, gas, and electric meters and uses a Web service as standardized and open communication interface. The recognition rate of a prototype implementation is 98 % and the measurement duration is approx. 1.5 seconds. The entire system was implemented on a Raspberry Pi as a cost-efficient hardware platform.

Index Terms—Internet of Things, Remote Meter Reading, Web Services, Computer Vision, Automation

I. INTRODUCTION

The vision of the Internet of Things (IoT) has great benefits like the increase of automation and integration. This leads to Smart Factories, Smart Grids, Smart Buildings, and Smart Homes, which can reduce costs and improve the quality of daily life. One possible application in the IoT is an efficient energy management. Nevertheless, for such an energy management a remote meter reading is necessary to measure the metering data over time. There are two ways to achieve remote meter reading:

- The installation of new smart meters, which are very cost-intensive (from 300 \$) [1] and furthermore, often use specific and proprietary communication protocols [2].
- 2) The cost-efficient extension of existing legacy meters with a communication module, to integrate them into the IoT.

For example, in Germany the installation of new smart meters is often unprofitable [1]. Therefore, to increase costefficiency and interoperability, we will focus on the second way to extend legacy meters with a communication module.

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In the literature, the most promising systems for automatic meter reading (AMR) are [3] and [4]. Unfortunately, due to their algorithms, they are inflexible concerning the meter model and instable concerning the point of view (distance, angle). Hence, these systems need a good alignment of the camera with the meter. Furthermore, these systems are evaluated with insufficient validation data. The main contributions of this research paper are the following:

- In contrast to the state of the art, we propose an universal approach rather than one solely for one specific meter type. This was mainly achieved by two algorithmic improvements.
- On the one hand, we propose a novel method for the detection of the regions of interest (ROIs). An ROI is an area of the image, in which the meter reading could be found. In contrast to the state of the art, the algorithm performs some kind of auto-alignment. This has two benefits. Firstly, the algorithm is more robust regarding angle and distance. Secondly, this gives the possibility to measure multiple meters with one system because it can handle more than one ROI.
- On the other hand a novel algorithm is proposed that can automatically detect the number of valid digits of the meter reading. Therefore, the approach can be applied to various meter models with an arbitrary number of digits.
- We validate the prototype implementation on a sufficient set of data. The data set consists of pictures taken from various angles, distances and brightness conditions.

Through the visual method of remote meter reading, the proposed approach can be applied not only to gas, water, and electric meters but also to other metering equipment. Since the system uses a Web service (WS) as communication interface, it has a high interoperability as well as plug and play functionality concerning the communication. The entire system is very cost-efficient (approx. 30 \$) and includes all steps from taking the image up to emitting the reading data over the WS interface. The system was implemented in C++ and is therefore very portable using no dedicated hardware. Nevertheless, the system exceeds the state of the art concerning execution time, while all of the related works run either on dedicated hardware or do not run on embedded

hardware at all. The proposed approach is called AMPERE (Automatic Meter reading using PattErn REcognition).

The remainder of this paper is organized as follows: in section II, the basics of this paper are introduced while section III gives an overview of the related work. Section IV explains the proposed system architecture. In section V, the experimental results are described and section VI concludes this paper.

II. BASICS OF PATTERN RECOGNITION

Firstly, a problem in pattern recognition called overfitting shall be explained. The overfitting of a pattern recognition system leads to the fact that the system performs very well on a specific set of data, while it performs very poorly on another one and also on real world data [5] [6].

Figure 1 illustrates that problem. The figure shows the measurement of the recognition error of a pattern recognition system, which was measured on two independent data sets. The error on the training data is used to adjust the parameters of the system during the training, consequently, the error on the training data is continually decreasing. Simultaneously, the error on the independent validation data is decreasing, too. Nevertheless, after a "sweet spot" the error of the validation data is increasing again, while the error on the training data is further decreasing. The pattern recognition system is "overfitted" to the training data in this case and thus not suited for real world problems. Generally, the problem of overfitting can be observed independently of the used classifier like artificial neural networks, fuzzy logic, support vector machines etc. [5] [6].

Overfitting can be avoided by using a huge amount of data for training and validation, as well as a data set that exhibits a high diversity. Furthermore, the data for training and validation should be as similar as possible to the data, that will be evaluated by the pattern recognition system in the field [5] [6].



Fig. 1. Overfitting of a pattern recognition system

III. RELATED WORK

Generally, all recognition rates stated in this section should be seen as approximate values because different validation sets are used. However, a comparison of recognition system is only valid if the same validation data were used [7], [5], [6].

In [3], Zhang et al. proposed a system based on a DSP platform. The recognition rate is stated as 99.7 % and the execution time as 2 seconds. Firstly, a threshold is applied. Afterwards, the region of interest (ROI) is extracted by horizontal and vertical projections. The digits of the meter reading are extracted as objects and afterwards a neural network is used for the digit classification. The neural network was trained with 700 pictures and validated with another 700. Unfortunately, the used method for ROI detection is basically a segmentation method, which struggles with homogeneous and difficult background [8]. Therefore, the camera needs to be aligned with the meter. Further, nothing is said about the validation data for the entire system.

In [4], a FPGA-based system is proposed by Castells et al. and the recognition rate is stated as 99.4 %. This approach uses no ROI detection at all and for the digit recognition the Needleman Wunsch algorithm as a sequence alignment algorithm is deployed. The entire system was validated with 396 images. Due to the fact, that no ROI detection is used, the camera has to be perfectly aligned with the meter. Additionally, no information is given about the diversity of the validation data.

In [9], a Matlab system is proposed, which achieves a recognition rate of 95 % being applied 200 pictures. For the ROI detection a segmentation and a connected component analysis are applied. Also, the aspect ratio of the ROIs is considered. The actual digit classification is not explained. Beside the information that the segmented digits are compared with patterns. The system was validated on 200 pictures. Again, the used method for ROI detection is basically a segmentation method, which struggles with homogeneous and difficult background [8]. Therefore, the camera needs to be aligned with the meter. Furthermore, the algorithm is not very flexible because of the fixed aspect ratio. In addition no information is given about the diversity of the validation data.

Further approaches can be found in [10], [11], [12] but these proposals are not explained in sufficient detail.

Altogether, all works stated above are neither very robust (distance, angle, brightness) nor very universal (meter model, meter type). None of the stated algorithms can handle with different meter models having an arbitrary number of digits. In all stated algorithms, the camera needs to be aligned to the meter reading. Although, the stated recognition rates are good, there is a high possibility that a pattern recognition system is overfitted to a specific problem, especially when the data for training and validation are not diverse, as stated in section II. As a result the pattern recognition system would not be very robust and will perform poorly on real world problems. Furthermore, [3] and [4] use dedicated hardware and in [9] the calculation is done on PC hardware.

IV. PROPOSED SYSTEM

A. System Overview

At the beginning, an overview of the proposed system architecture shall be given. A corresponding diagram can be found in Figure 2. Furthermore, Figure 3 shows images of the different stages. Every step shall be described in more detail in the following:

- **Image acquisition:** Firstly, a camera is used to take an image of the meter. The taken image is in gray scales without color to reduce the computational complexity of the entire system.
- **Preprocessing**: Then a preprocessing is applied. It only cuts out the middle of the original image by a size of 900 x 600 pixel. Once more, this is done to reduce the computational complexity of the entire system. The proposed approach could also be applied to the whole image.
- **ROI detection:** Afterwards, the ROIs are extracted. These are the regions, in which the meter reading is assumed. The ROI detection has the benefit that the following segmentation is only applied to a part of the image.
- Segmentation of the ROI: In this stage, the ROIs are segmented individually into the foreground objects and the background. The results of the segmentation are improved, due to the fact that the segmentation is applied to the ROIs and not to the entire image because segmentation methods always struggle with inhomogeneous backgrounds [8].
- Search for a chain of objects: After the segmentation, a distinction between the digits of the meter reading and other objects is required. Therefore, the prior knowledge is used that the digits of the meter reading form a chain of objects having nearly equidistant gaps. This step has the benefit, that the system automatically determines the quantity of valid digits of the meter reading and the digits themselves.
- **Digit classification:** Finally, the foreground objects (digits) are classified and for each object the corresponding digit is determined.
- Save meter reading: After every digit was classified the resulting meter reading is saved.
- Emit meter reading: After the meter reading was saved it can be emitted. More than one reading can be found, e.g., due to other areas in the image including digits. When more than one meter reading was found, the reading including the most digits is the most presumable one and therefore assumed to be correct.

In order to determine the recognition rate of the pattern recognition system no prior knowledge is used. Prior knowledge could be, e.g., that the position of the meter reading is static and the value of the meter reading can never decrease. Following, we will only explain essential steps in full detail.



Fig. 2. System architecture



Fig. 3. Images of the different stages, a) Input image, b) Image after preprocessing, c) Detected ROI, d) Segmented ROI, e) Single extracted digit

B. Detecting the Regions of Interest

This section describes the detection of the ROIs. The aim of the ROI detection is to extract parts of the image that might contain the searched area (in this work: the digits of the meter reading). The basic idea is that a part of an image is always easier to segment than the whole image [8]. Statistical classifiers like neural networks are reaching excellent results in the ROI detection [7]. Unfortunately, there is no suitable data set available to train such a classifier and an insufficient data set would result in overfitting as described in section II.

The approach for the detection of the ROIs is based on vertical edges in the image. The basic idea is that in the area of the meter reading, there is a local accumulation of vertical edges. Related algorithms based on vertical edges are already reaching good results in the license plate recognition [7]. The algorithm, which is proposed in this work comprises the following steps:

- Convolution of the image (gray scale) with a matrix that calculates the horizontal derivation and is thus sensitive to the vertical edges in the image. So a vertical edge image of the original image was created.
- 2) In the next step, the edge image is convoluted with

a mask of a square form. Hereby, a local averaging of the edge image is achieved. The resulting averaged edge image highlights the regions were the most vertical edges can be found.

- Finally, a threshold is applied to the averaged edge image to segment it into the highlighted foreground objects and the background.
- 4) The foreground objects correspond to the regions with the most vertical edges in the image and are assumed as the ROIs.

The steps of the algorithm are visualized in the Figures 4, and 5. The matrix used to calculate the horizontal derivation is similar to the matrix calculating the horizontal derivation in the sobel operator. The matrix looks as follows:

$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$



Fig. 4. Input image after vertical edge detection



Fig. 5. ROIs found in the input image

C. Segmentation

After the ROI detection, the extracted area is wider than the actual meter reading and therefore the background is not perfect homogeneous. In this case, a local/adaptive threshold is required. The applied local threshold technique calculates a particular threshold for every pixel. For the calculation of this individual threshold, the gray values of pixels in the surrounding area are weighted with a Gaussian function and added up. The thresholding was, e.g., done by the OpenCV function *adaptiveThreshold*.

D. Search for a Chain of Objects

In this work, a novel step is inserted between the segmentation and the digit classification. The search for a chain of numbers is applied to the foreground objects, to distinguish between digits of the meter reading and unwanted objects. It would also be able to set the required number of digits to a fixed value, but by applying an algorithm to search for a chain of objects, the flexibility of the proposed system in increased. The number of valid digits is automatically determined by the system. Thus, it can be applied to every meter model having five digits or more. The proposed algorithm uses prior knowledge and checks four conditions:

- There should be an equidistant horizontal distance between the digits.
- There should be only a small vertical distance between all digits.
- All digits should have approximately the same width.
- All digits should have approximately the same height.

Figure 6 illustrates the position of the parameters in a native image. When the conditions mentioned above are true for five or more foreground objects, these objects build a line and are assumed as the digits of the meter reading. The number of at least five objects was chosen because nearly every meter has at least five digits.



Fig. 6. Parameters of the algorithm to search for a chain of objects, h = height, w = width, dv = vertical distance, dh = horizontal distance

E. Digit Classification

For the digit classification, a neural network is deployed. Artificial neural networks are reaching the best results in the field of digit classification and character recognition. The very best results were achieved by so called convolutional neural networks by Ciresan et al. [13]. Nevertheless, in this work we use an multilayer perceptron because Ciresan et al. showed in [14] that multilayer perceptrons can achieve recognition rates as high as the ones achieved by convolutional neural networks. Moreover, multilayer perceptron are supported by many software libraries. As mentioned before, it is necessary to train a classifier with a sufficient training set, to avoid overfitting. To achieve a training set as huge and various as possible, the training images were obtained from the following three sources:

 Firstly, training images were received from the ICDAR-2003 robust reading data set, which is still used to verify many character recognition systems. Indeed, only the digits of this data set are used because the digits of the meter reading are not expected to be literals.

- Secondly, the digits from real images of electric, water and gas meters were extracted to get some images from the real field of application of the proposed system.
- Finally, artificial images of digits were created and those were distorted with white Gaussian noise. This is a valid possibility to extend an existing data set referring to [6].

From all those sources, a total number of 907 training images were received. Figure 7 shows one example image from every of these three sources.



Fig. 7. Examples for the zero digit from the training set, a) taken from a real image of an electric meter, b) created digit distorted with noise, c) image taken from the ICDAR-2003 robust reading data set

F. Emit Meter Reading

In the final step, the meter reading is provided and emitted in the local network. For the network interface, a Web service (WS) was chosen. WSs have many advantages like high interoperability or plug and play functionality. The WS was implemented in JAVA using the JMEDS library, which is suitable to embedded devices. Figure 8 illustrates the structure of the WS. The service has two operations:

- **GetReading:** This operation can be invoked by a client and returns the current meter reading.
- MeterReadingSubscription: Clients can subscribe to this operation and are notified when the meter reading changes. Thus, a perfect measurement of the meter reading data over time is provided.



Fig. 8. Structure of the Web service providing the meter reading data in the local network

V. EXPERIMENTAL RESULTS

After the concept of the system was proposed, we will now focus on the used hardware and software as well as present the experimental results of the prototype implementations.

A. Hardware

The Raspberry Pi model B was used as cost-efficient hardware platform. Further, the Raspberry Pi camera was used to take images of the electric meter. Also, a lens was used to adjust the focus of the Raspberry Pi camera from its default value (approx. 2 m) to a more reasonable value (approx. 0.5 m). The entire prototype consisting of the Raspberry Pi and the camera costs approx. 30 \$.

B. Software

The system was implemented twice using two different work flows. In the first approach, the system was implemented in Matlab and afterwards C++ code was generated from the Matlab code. In the second approach, the system was implemented in native C++ using the OpenCV software library. Both systems were executable on the Raspberry Pi and the Raspbian OS.

C. Experimental Setup

This section describes the experimental setup, in which the validation data were generated. The validation data are generally not used to train a pattern recognition system but to evaluate it [6].

Unfortunately, there is no common set of validation data in the research field of automatic meter reading. Thus, a new data set needed to be created. For this prototype it was sufficient to create the validation data with one meter model but the data can be extended easily. Nevertheless, the validation data should be as diverse as possible to allow a valid evaluation of the proposed approach. In order to increase the diversity of the validation pictures, these were taken from 9 different measurement points including 3 different distances and 3 different angles per distance. From every measurement point, images of 10 different meter readings were taken. While the first 3 digits of the reading were fixed, the last 3 digits were changed from "000" to "111" and so on until "999" was reached. Furthermore, the images were taken under 2 different brightness conditions: natural light and artificial light. The total validation set consists of 9 * 10 * 2 = 180 images. Figure 9 illustrates the experimental setup including the points of measurement.

Through the different angles, distances and brightness conditions the diversity of the validation set is increased and thus, the overfitting of the system is prevented.

D. Comparison of the Implementations

The different implementations shall be compared in the following. Table I summarizes the measured values for the execution time (extraction of one meter reading) and standard derivation. The execution time was measured on the Raspberry Pi model B and the recognition rate of 98 % was measured on the entire validation set.

The system implemented in Matlab needs a long execution time of 152 seconds, while the system implemented in OpenCV has an execution time of only approx. 1.5 seconds. It is comprehensible that the Matlab system consisting of C++



Fig. 9. Experimental setup and measurement points according to the positions of the camera

Library	Exc. Time [s]	Std. Der. [s]
Matlab	152.576	53.326
OpenCV	1.458	0.072
TABLE I		
MEASUREMENT RESULTS		

code derived from Matlab code can never be as fast as native C++ code.

It has to be remarked, that the recognition rate could be improved further with using prior knowledge. The system could be easily extended taking many images and saving all recognition results, while emitting only the median value for every digit. Also, the problem to detect the least significant digit, which is continually moving could be solved this way.

E. Comparison to Related Work

In [3] and [4], very good recognition rates were stated but this must be questioned. In both works there is no information about the used validation data or their diversity. Furthermore the stated recognition rates are very high and thus implausible on such small training sets. Though the probability is high, that those systems were overfitted. For comparison Chang et al. reached in their rewarded work on license plate recognition a lower recognition rate of 97.9 % using a much more reasonable validation set of 1088 images taken in native scenes [15].

The proposed system was validated using data being as diverse as possible. Therefore, the measured recognition rate has a high validity. Furthermore, in this work an universal approach is proposed, which is suitable to various models (gas, water and electric meters) and environment conditions (angle, distance, brightness). In [3], the used ROI detection is susceptible, e.g., when the images are not taken in an rectangular angle and in [4] there is no ROI detection at all.

VI. CONCLUSION

In this paper, we propose an universal and cost-efficient approach for remote meter reading. The proposed approach exceeds the state of the art due to algorithmic improvements. We propose a novel method for the region of interest detection as well as a novel algorithm to detect the number of valid digits of an arbitrary meter. Hereby, robustness (variable angles, distances, brightness conditions) and adaptivity (support of various meter models) are increased. The system uses a Web service as network interface providing interoperability as well as plug and play functionality. This opens up the possibility to develop intelligent, distributed systems, e.g., increasing energy efficiency. Furthermore, we compare different prototype implementations. The entire system runs on a Raspberry Pi as cost-efficient hardware platform. The prototype reached very promising results with a recognition rate of 98 % and an execution time of only approx. 1.45 seconds. Both were measured on a sufficient validation set.

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