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Developing Inspection Robot for Corrosion Detection in Pipes by Image Processing Method

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Abstract
Corrosion of transmission pipes causes wear and failure of systems, and other disadvantages include financial losses for replacing the system, maintenance costs, system failure and the need for repairs, contamination of products. In contact, leakage or destruction of products and causing danger to life is indicated. Therefore, in this paper, the method of checking and detecting the location of corrosion and detecting the level of corrosion for timely repair and replacement of parts is presented. The proposed method is based on image processing algorithms, and as a result, it is included in the category of non-destructive inspection methods. The innovation of the proposed method is both in providing a new processing algorithm for identifying corrosion and in providing a suitable lighting method. In this method, first the correct lighting is done and then the images obtained from the inspection are pre-processed for the identification stage. Image pre-processing includes changing the color format, removing noise and smoothing. Then the corrosions are identified by the edge detection algorithm and their amount is estimated by morphological operations. The results show that the presented method has been able to accurately detect corrosion in complex pipes.

Keywords: Corrosion, image processing, Fault detection, Edge detection algorithm

1. Introduction
Industries need to maintain systems in order to reduce costs, and to prevent system erosion, it is considered the first requirement to identify the places that are being eroded, so that by knowing the location and type of erosion, they can use the appropriate method to prevent and control it. Various researches (Mohammed et al., 2018; Diaz et al., 2018) have been conducted in recent years to investigate different methods of fault detection in transmission pipes. Among the corrosion detection and inspection methods, we can mention acoustic, radioactive, thermal, electromagnetic, infrared, ultrasonic waves and magnetic flux methods (Li and Johan 2013). Meanwhile, non-destructive methods are given more priority

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(Niu et al., 2021). Imaging methods are used in non-destructive methods for use in small-sized pipes where human movement is not possible, and in recent years this field of research has become more important. For example, miniature robots with wheels in pipes have been considered in the field of non-destructive testing. Their availability and security have given them many uses in places where manual inspection is impossible or unprofitable (Dobie, Summan et al. 2013). CCTV cameras play an important role in these systems. In the old methods, an operator filmed inside the tube and the data was recorded in a device. This transmission was done by wire and in long distances such as gas pipes, petrochemical and oil industries, it caused many problems and reviewing these images required a lot of time, energy and money. On the other hand, the review was based on people's experience, which was associated with many errors (Mashford, Rahilly et al. 2010).

In the research (Safizadeh and Azizzadeh 2012), ring lighting is used from the center of the pipe and data processing is done only with the reflections from the surface of the pipe. In this method, the holes are well defined, but a proper measure of corrosion and its extent is not provided. Meanwhile, the lighting done has low accuracy and the difference in light intensity in different parts is quite noticeable in the image, of course, the way of lighting is uniform. The inside of the pipe seems to be one of the problems of most of these systems. In this method, corrosions are identified by strong light reflection. It should be noted that the corrosions are considered only in the form of holes, and attention to sedimentation, deformation or surface corrosions is not mentioned. The method presented in (Dobie, Summan et al. 2013) examines the images taken by cameras perpendicular to the surface. This method is not effective inside the tube because the number of cameras increases and the lighting becomes difficult, while the amount of data increases and the analysis takes time. In the paper (Mashford, Rahilly et al. 2010), images are analyzed by morphological and SVM algorithms and features based on RGB and HSB color spaces. In this method, the image is segmented into different areas and the main goal is to segment the pipe and its connections. The algorithm in (Choi and Kim 2005) analyzed the types of corrosion using vertical images of surfaces and processing methods of color, texture and edge features. Among the methods presented in this article, the HIS method has been approved. The results of this article are very suitable for free surfaces, but inside the tube, the problems of this type of imaging will bring limitations.

The proposed method in this paper is based on the imaging of the cross section of the pipes, and smoothing algorithms, edge extraction and morphological operations are used to detect corrosion. Also, imaging method, hardware considerations and how to process images are presented.

2 Method

According to the works (Karthik et al., 2021; Zhao & He, 2021), it can be said that in most cases CCTV cameras have been used to control the operator and even for automatic or manual optical control system. This type of imaging and data analysis have been associated with many problems, and the problem of good image and proper lighting have always been among the most basic problems. In this section, we will examine two types of video cameras in order to increase the accuracy and quality of the images, and then we will try to improve the lighting inside the tube with the two suggested methods, and finally, we will process and improve the resulting data with two methods.

2.1 Pipe simulator system

In this design, similar to the method presented in (Safizadeh and Azizzadeh 2012), a six-inch metal pipe with a thickness of 6 mm, which is one of the most widely used pipes in the industry, is used, and the leakage of pipes is simulated by drilling holes. In this method, we will try to check the accuracy and detection power of the system by creating holes with different diameters. For this purpose, drilling with drill tools and drills with diameters of 2, 3, 4 and 5 mm have been used. In addition, in this article, in addition to the investigation of leakage detection using the automatic video surveillance system, a new topic in video surveillance systems will be investigated with the aim of investigating the sediments inside the pipe, which is used to create these deposits from the soil inside the pipe. Of course, this mode has already been done in manual systems (i.e. using a human user), but it has not been discussed in automatic systems. The figures 1 and 2 show different views of the test tube, holes simulating leakage and deposits.

Figure 1: Vertical view of the test tube

Figure 2: Cross-section view of the pipe and sediments inside it

In this system, we use a quality computer as a processor (see Figure 3). It should be noted that the specifications of this system do not require a very powerful processor or memory, and the processing is done with a very simple system. We use MATLAB software for data processing. We made the conditions of the environment around the experiment the same as the condition inside the soil of absolute darkness so that the results are more real and the ambient light does not affect the lighting. To take photo from inside the pipe and move the camera inside the pipe, we used a special long stand, which, in addition to easily moving the camera inside the pipe, tries to keep the camera fixed and in the center so that the navigation conditions can be simulated by the robot. The movement of the cameras inside the tube was done at a constant speed, and the data was recorded at a video recording speed of 20 frames per second, and at a photo shooting speed of 1.500 seconds (the speed of taking a complete photo).

Figure 3: Recommended system hardware

Due to the short length of the test tube to create natural conditions and simulate the full length, align the placement of the tube with a shiny wooden plate that is 2 meters away from the end of the tube and at an angle of 60 degrees to the cross section of the tube. We were supposed to deflect the reflections inside the tube so that it does not affect the principle of the experiment. In order to store this data, according to the facilities provided by the manufacturer, you can take pictures using the web or the specialized software of Hikvision cameras called IVMS-4200 for use in Windows. In this research, this specialized software was used for imaging.

2.2 The first proposed system to improve the quality of imaging and lighting

In the previous systems, analog systems were used for filming inside the tube. These systems supported the advantage of soft image and the ability to adapt to light conditions, but on the other hand, in data transmission in wired or wireless form. Due to the need for long distances, there was a significant loss of quality, on the other hand, to process these images, the data must be digital, and for this purpose, analog to digital converters were used, which greatly improved the images. In this conversion, they found a loss of quality, but with the advancement of technology in the field of digital cameras, the problems of light processing and high quality led us to investigate this type of cameras. In this new system, there will be no loss of image either in wireless or wired imaging, because if the digital data reaches its destination, there is no concept of loss in it, and its transfer and even storage is far easier. It is easier and does not need analog to digital converters.

For the imaging stage, first, a camera was selected that has a fixed lens and general focus, like the cameras used in previous articles, and only the image and optical characteristics of the camera were paid attention to. The proposed camera lens should be wide and have the possibility of shooting with a wide angle due to the placement of the camera in the system parallel to the tube axis. For this purpose, we recommend a 2.8 mm lens with a 1.3 inch optical sensor up to a wide angle. Approximately 105 degrees (which is much more than analog cameras) is recommended. 3 megapixel camera (2048 x 1536 pixels at 50 Hz) with light sensitivity of 0 to 0.07 lux in infrared mode, with 3D and 2D digital noise reduction system provides good results in current digital cameras for tube environment. In the current systems, the image compression system is done with H.264 mode and images are transferred to the network system using category 6 wire or wireless network data transmission technology. Of course, in addition to data transmission, they have the possibility of transmitting energy consumption from the same interface cable using the standard electricity through the network. In this standard, the system considers the length of the wire and optimizes the energy consumption of the system and reduces the energy consumption. This data is entered digitally directly into digital systems and computers because it uses the public port of most digital systems, with these necessary specifications in the first proposed design of the factory-made camera model DS-2CD2432F-I Hikvision in China seems very suitable. The image of this camera can be seen in the Figure 4.

Figure 4: The first suggested camera with spot lighting

As seen in the above image, this camera uses a concentrated light source that is renewed by infrared method. According to the previous articles, this type of lighting was proposed as the first type, with the difference that this camera uses modern technology called uniform infrared lighting, which is considered an invention of the camera manufacturing company. In this system, a special type of lens is used to spread infrared in the environment, which will result in uniform lighting in the environment. The reason for choosing this company was this technology because according to previous articles, non-uniform lighting causes many problems in imaging and data analysis.

2.3 The second proposed system to improve lighting and imaging

A kind of lighting has been offered for CCTV systems, which, unlike the previous one, which uses a concentrated light source with a lens, uses a large number of concentrated sources gathered around the camera. Our reason for the second proposal in this research is to examine the lighting inside the tube using the wide lighting method and compare it with focused lighting, which has not been addressed in past research (see Figure 5). For the second stage of imaging, in addition to the specifications presented in the first proposal, a lens with the ability to adjust magnification and manual focus has been used, which adjusts the focus on the wall of the tube to provide a better image.

Figure 5: The second proposed system with extensive lighting

For this purpose, it is recommended to use the camera model DS-2CD2632F-I made by Hikvision company, made in China, with the technical specifications presented in the section.

2.4 Proposed image processing method

In this section, we explain the proposed image processing algorithm. This proposed method works fully automatically and does not require any monitoring operations or human intervention. Of course, the recorded images are provided to the user, but there is no need to manually adjust the parameters and the human user to detect corrosion. The images obtained from infrared cameras have the appearance of gray level images, but due to the considerations taken by manufacturers, most of the images are saved in RGB image format. In the first step of the algorithm as image pre-processing, its type is changed from RGB to gray level. This does not change the appearance of the image and only reduces the amount of computing and data storage. For example, the left side of Figure 7-4 is an RGB image that is m*n*3 data. m and n represent the number of rows and columns of the image, respectively, and the third dimension of the RGB image represents the amount of red, green, and blue colors to create the color of each pixel. The right side of Figure 6 is the gray level transform of the left image. As you can see, no details of the image have been changed, only the amount of data has been reduced to an m*n matrix. The number corresponding to each pixel varies between 0 and 255 between black and white, this is the reason why this type of image is named as gray level image.

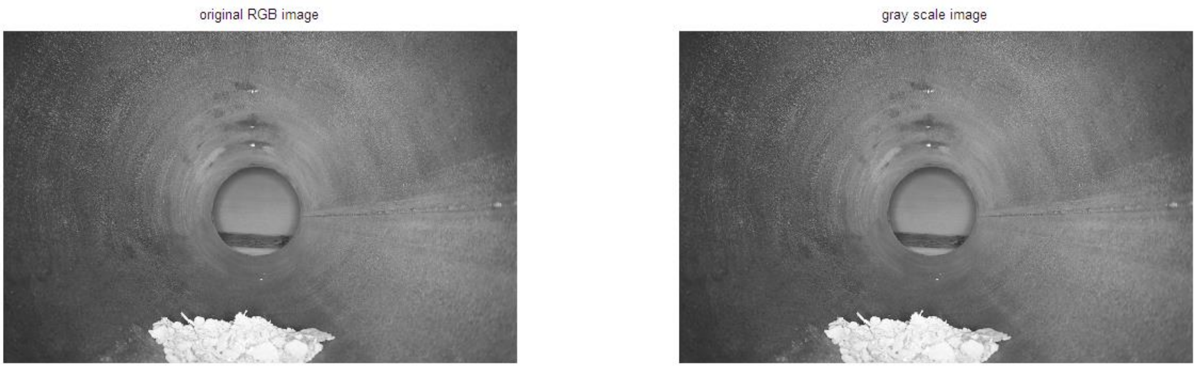

Figure 6: Left: original RGB image, right: equivalent gray level image

After obtaining the gray level image, existing algorithms are used to remove noise and smooth the image. The reason for the smoothing of the image is that most of the pipes do not have a completely smooth and polished surface, and their rough texture may also be detected as corrosion in high-precision inspections.

Smoothing is a suitable method to prevent such a problem, and in addition, the possible noises resulting from the vibration of the camera during movement in the tube are also removed. There are many algorithms for smoothing, including averaging filters with different kernels, averaging and Gaussian. In this article, averaging filter with circular kernel is used. This filter, which is simple at the same time and has little computational complexity, provides very good results and prevents the extraction of unnecessary edges in the next step of the algorithm.

Figure 7 and 8 shows an example of the edge extraction step without image smoothing and with image smoothing. As can be seen, if the image is not smoothed, the lines and the inherent texture of the pipe are also identified as edges, and as a result, there is no difference with the areas that have edges caused by corrosion. But in Figure 8, where the edge extraction is performed on the smoothed image, only the edges related to corrosion are identified.

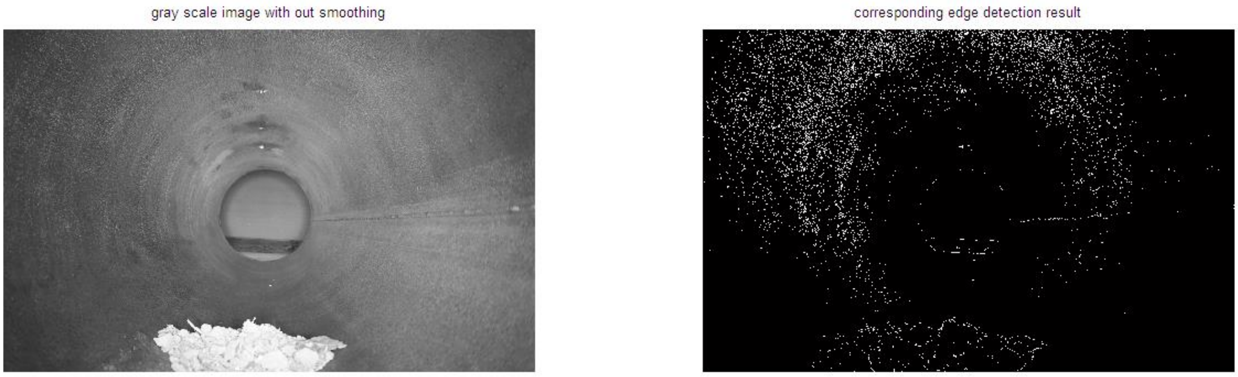

Figure 7: Unsmoothed image and corresponding extracted edge

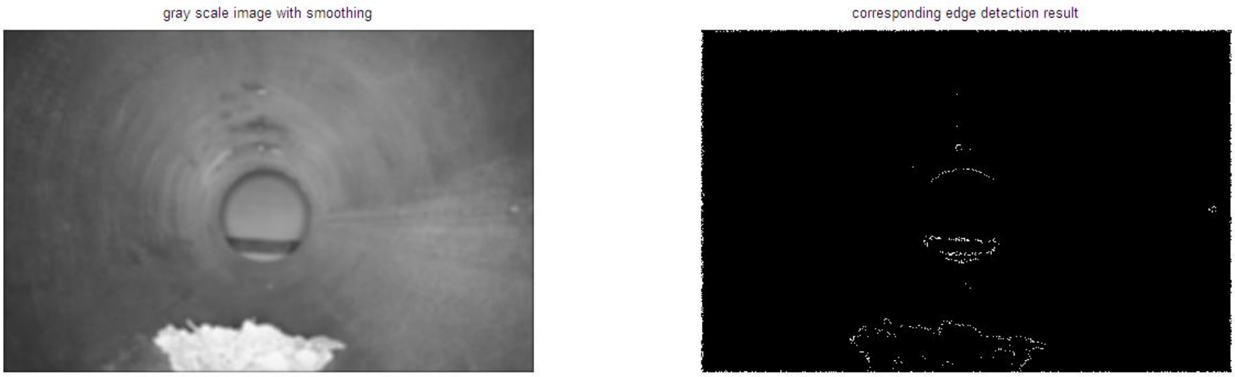

Figure 8: Smoothed image and corresponding extracted edge

As mentioned, after smoothing the image, the edges in the image are revealed. The edges represent changes in light intensity in different areas. Due to the fact that the presence of a foreign object or hole in the tube causes new edges to appear in the image, this principle has been used to determine the corrosion areas. Sobel, Pruitt, Robert and Kenny algorithms (Han & Zhu, 2022), which are famous edge extraction algorithms, have been investigated for this purpose. You can see an example of the implementation of these edge detection algorithms in Figure 7. There is no major difference between these algorithms, but according to the obtained results, Pruitt's algorithm was chosen for checking the images due to the correct details detection. As seen so far, the images in question are complete images of the cross-section of the pipe. This is despite the fact that different areas of the image have different light intensities and viewing angles according to the distance and proximity to the camera and light source, and the integrated examination of these areas is practically incorrect. For this reason, valid ring areas near the camera are considered and only the edges in this area are checked.

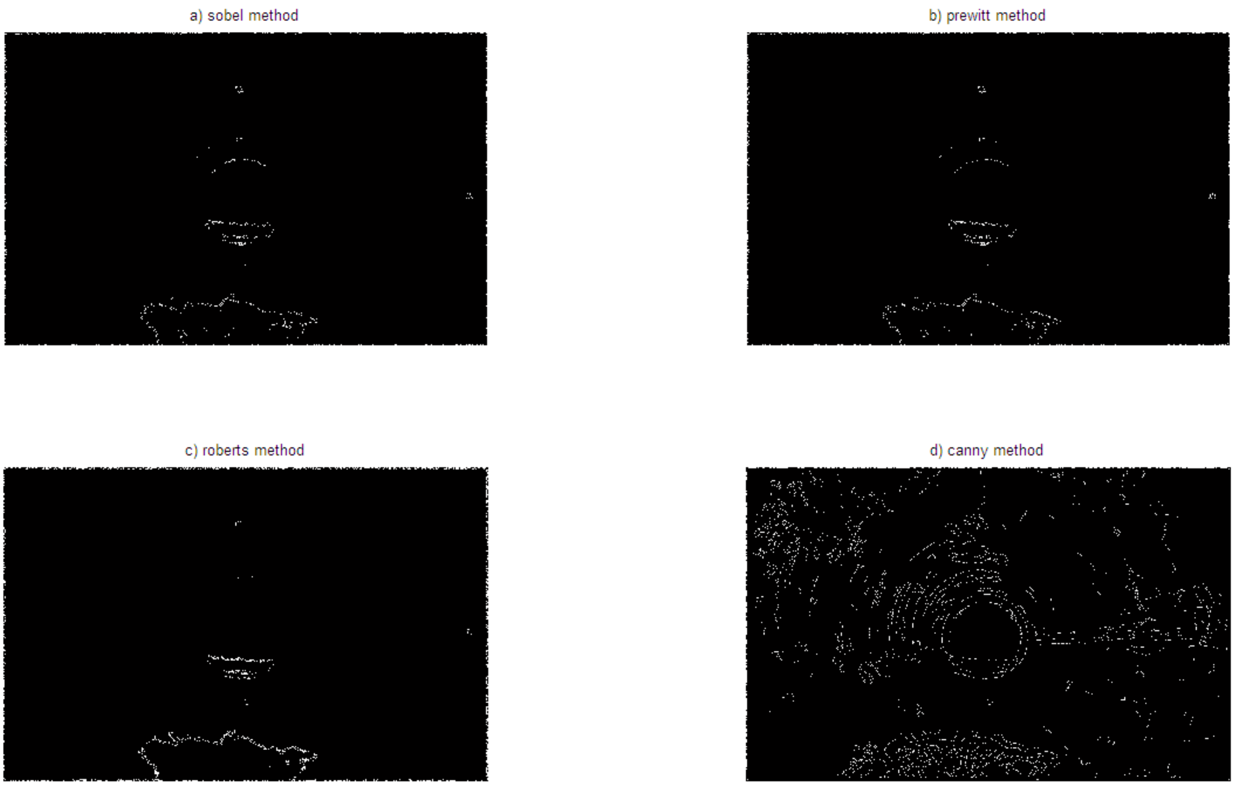

Figure 9: The results of four different edge detection algorithms

The question may be raised as to why these areas were not separated from the beginning of the work. The reason for this is that if the invalid areas were removed at the beginning of the algorithm, an unnatural border related to the removal operation would be created in the image, and as a result, even in the areas where there is no corrosion, the high edges that are the result of this removal were extracted. For this reason, in the proposed algorithm, first all the edges were extracted and then the less valid edges were removed. Figure 8 represents this area on the original image. As can be seen, in the ring close to the camera, the radiation is completely uniform. The green circle is the lower limit and the blue circle is the upper limit of this area. Figure 10 shows the process of edge extraction and removal of edges related to scattered areas.

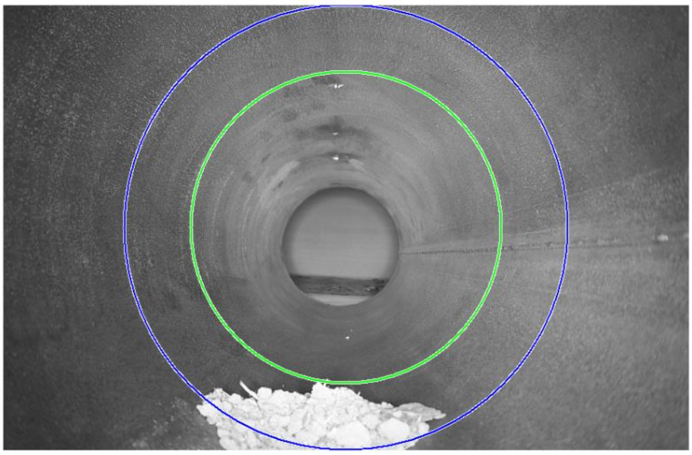

Figure 10: Valid range considered for corrosion search

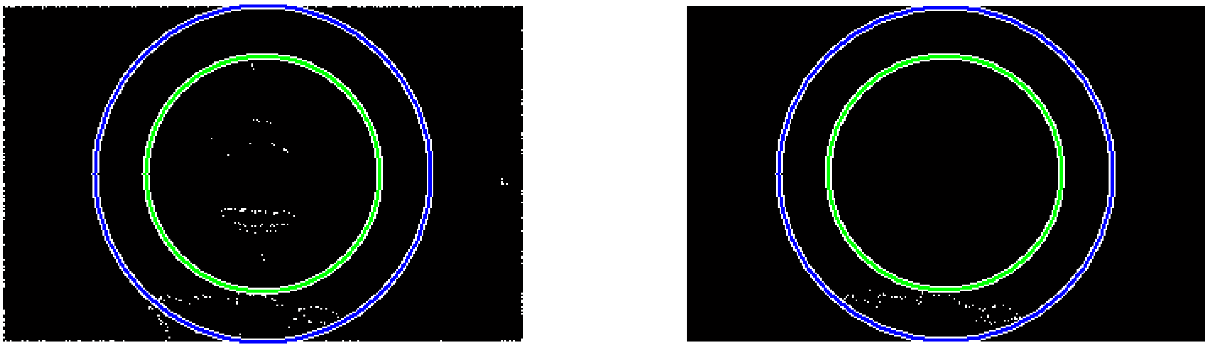

Figure 11: The process of edge extraction and removal of edges related to invalid areas

Extracting the edge alone can be enough to determine whether there is corrosion in the image under investigation or not, but for a better understanding of the severity of corrosion or its area, it is suggested to use morphological filters. First, we connect the edges close to each other that belong to the same corrosion area with the thickening operation, and then we fill the areas surrounded by closed borders. Figure 12 shows an example of this operation.

Figure 12: Left: edges of the valid region. Right: thickening and filling process

In order to determine the amount of corrosion in different images, we define the parameter of the amount of observed corrosion as the ratio of the extracted corrosion area to the total valid area under investigation as follows (Li et al., 2020):

$$corrosion.visiblity = \frac{corrosion.area}{total.valid.search.area} = \frac{S_{corrosion}}{S_{search.area}} \tag{1}$$

The value of this parameter changes between zero and one. The closer this number is to zero, the less visible corrosion is. It is important to note that this parameter only gives us an approximation of the visibility of corrosion, and this does not mean the severity of corrosion. For example, the intensity of corrosion in holes is very high and the damage caused by these corrosions is very high, but if the hole is small, the rate of observing this phenomenon will be low. However, the non-zeroness of this parameter in an area indicates the presence of corrosion in that search area.

3. Results

3.1 Results of the first proposed system

As explained in the previous section, the 2432 camera was used for the first test, which produced the results as shown in the Figure 13.

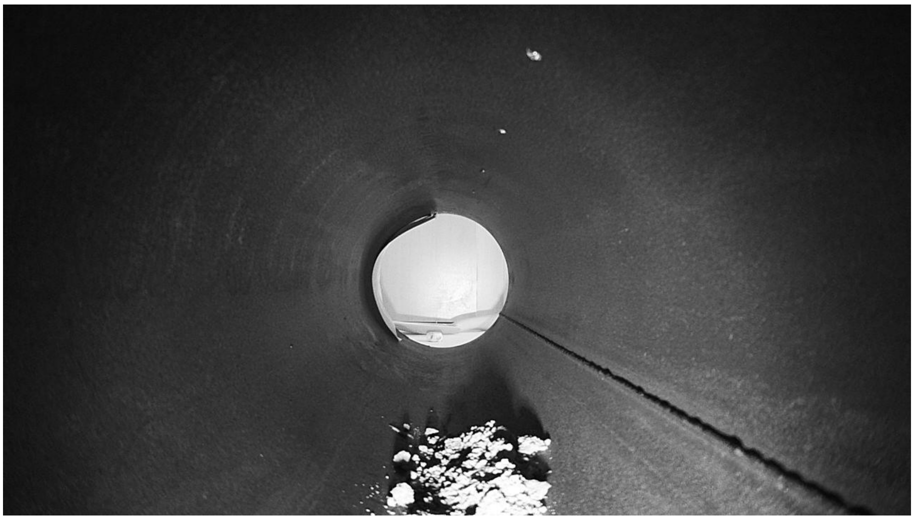

Figure 13: Sample image from camera 2432

As can be seen in the image above, in this type of imaging, the leaks are well defined and the holes can be detected with very high accuracy, and the possibility of data analysis can also be done easily. But in non-level cases such as deposits, changes in the shape of the pipe, or depressions, it creates shadows in the image, of course, this seems quite reasonable in this type of lighting, because spot lighting always borders the shadow. creates a complete In this image, it is clear in the sediments and welding of the pipe and it makes the data defective, this causes mistakes in the automatic analysis or even by the user, because if the leakage is in the shadow of the sediment or the change of the state of the pipe (which is mostly susceptible to corrosion or leakage) neither the user nor the processing system will notice it. In this test, the user can easily identify the defective points (either leakage or corrosion or change of state or sediment) and distinguish them from the bend. Since clearly the difference of each and the intensity of reflected light will determine the type, state and area of defects. As it is clear from the data, the proposed camera type is very suitable in terms of image quality, light sensitivity and viewing angle, but problems are seen in the following cases.

1- Lighting: point lighting due to the small diameter of the pipe and the low height difference between the center of lighting and the sediments, a long shadow is formed, which has a full shadow due to the properties of point light. This shadow destroys a part of the tube's vision and puts it out of our reach. In order to solve this problem, we propose a wide light source for the first time in these systems, because it has both a much less shadow and a brighter shadow. We have added this problem to the system in the second proposal.

2- Focal distance of the camera: as the figure shows, due to the closeness of the tube to the camera, the image does not have sharp edges and has caused a lot of blurring in the image. Of course, this problem is less at distances farther from the camera, but for more details, closer images work much better, and also at closer distances, the shadows are also smaller. We used manual focus center so that we can obtain high-quality sharpness at a greater distance to the target.

3- The light source not being in the center: due to the fact that for the automatic detection of the results, it was necessary to place the camera in the center of the tube, it was no longer possible to place the light source in the center of the tube, which itself causes the difference in light intensity on the sides of the tube. Previous articles can be seen and they have not tried to fix it. In order to solve this problem and taking into account the first problem that we solved with the wide light source proposal, we will place the camera in the center of the light source to create a diffused light in the tube, of course, to prevent direct light reflection in the lens of the wide source camera. The light should be slightly behind the camera.

3.2 The results of the second proposed system

The characteristics of the second camera were examined in the previous section, considering the problems in the first proposal, it seems to be the best option for an ideal image. An example of this camera's images shows this.

Figure 14: A sample image of the second camera

As it is clear, there are no shadows in the new image and a completely uniform light has been obtained in the tube. A noticeable increase in the quality of the image quality compared to the previous state can be seen to the extent that the texture of the pipe can be recognized. Imaging from inside the tube is considered. The user can detect any kind of defects easily and without any problems and can identify these defects without any shortcomings because it is not possible to magnify in this size in the eye inspection in the movable tubes of people.

3.3 Comparison and conclusion between two proposed systems for data collection

Considering that the data obtained from the second proposal did not have the problems of the first proposal and all the images were ideal and fully satisfied our purpose, then the second method is recommended.

4. Conclusion

The proposed method has examined two important factors, including the appropriate operating solution for efficient imaging and the appropriate processing algorithm, and has presented a new method in both fields, and the effectiveness of the proposed methods has been proven by showing the results. Providing a suitable lighting method and a corrosion detection algorithm with high speed and accuracy and in a fully automatic manner is one of the advantages of this proposed method over the previous methods. Due to the fact that the lighting in the vertical section is done uniformly and the search areas were selected in the part that had uniform light in the direction of the pipe, the uniformity of the lighting in both directions has been ensured. In addition, a parameter has been introduced for the visibility of corrosion. Although this parameter is only a scalar value, it contains two types of useful information. First, if this number is not zero in an area, the presence of corrosion in that area is determined, and secondly, the size of this parameter is a measure of the size or smallness of the corrosion level. Due to the fact that the depth of corrosion in this research is not known, it is not possible to comment on the severity of corrosion. As a result, the use of stereo images to calculate depth is suggested for future work. The use of stereo images with cameras that have been previously calibrated to each other provide 3D information inside the pipes. These three-dimensional information, in addition to width and length (which were available in two-dimensional information), also include height information or so-called depth of the image, and as a result, with their help, the amount of sediment or the depth of cracks and holes can also be determined.

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