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Research Article

INTELLIGENT VISION BASED MOBILE ROBOT FOR PIPE LINE INSPECTION AND CLEANING

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ABSTRACT

Development and advancement in technologies lead to constant change in the fluid transportation systems. In recent years, fluids are moved through pipes laid above and below the ground and water level. These fluid are readily react with the carrying pipes and need consistent maintenance and repairing, which is a difficult task for humans, as they carry toxic chemicals, fluids, lighting, toxic gas, low pressure and most of the time has small internal diameter or bends which become inaccessible to human. To overcome the problem of cleaning, in this research, an intelligent internal pipe cleaning robot using vision system had been developed. The developed robot can move through the interiors of the pipes using independent motors and flexibly adjusting wheels. The vision system has been used to capture the pipe interiors. The image had been interpreted using artificial neural network and the output has been given to the controller and in turn it will clean or move to the next segment. The experimentation had been conducted with virtual pipes and the performances were found satisfactory.

INTRODUCTION

Day after day, technological improvements are advanced in making the system with more flexibility, accuracy, security, controllability, monitoring and maintenance of the system with the help of digital machines. Varieties of intelligent systems are designed and used in all the areas of the engineering to reduce the human fatigue and automation with high quality outputs. Among these intelligent systems, robotics plays a major role starting from toys till the space machines. Robots are categorized based on the task it carried out such as industrial robots, automobile robots, material handling robots, medical robots, humanoid robots, service robots, etc. Service robots are the specific type of robots to do specific tasks which the humans found difficulty and having more fatigue. Such service robots have found application in servicing, inspection and maintenance, which replaces the humans, mostly in the substandard working conditions and conditions having health danger, especially in inspecting underground installations such as pipelines for water, gas, oil and sewage. The inspection of pipes became essential as to check the corrosion level of pipe, sediment blockage formations, recovery of usable parts, burs from pipe interior, crack formations, sampling of sludge, scale formation on pipe internal surface, inspecting complicated geometries, various pipe diameters, etc. This research has concentrated in the development of intelligent service robots for inspection and maintenance of the fluid transport piping system equipped with the required sensors and controllers. In this work, camera has been provided with the transmitter section and digital machine in the receiver section. The image captured by the camera will be transmitted through the transmitter section consist of four switch to give four orders and receiver section receives the input for the robot action such as movement direction, cleaning motor actuation, scrubbing motor actuation and sediment removal.

Infrared and ultrasonic sensors work beside with the controller to detect the obstacles and identify the alternate path for movement. Once the digital machine receives the image from the robot, then that image have been processed using image processing algorithm and given as input to the artificial neural network for interpretation and to take suitable decision for further action. Various experiments had conducted in the virtual environments to improve the inspection efficiency by reducing the time, manpower, improving security and efficiency. Thus the developed robot improves the effectiveness of the inspection, reduces the cost and thereby increases the profit margin.

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Literature Survey

Service robots or automated structures can have a wide range of applications in situations where the conditions for operators are threatening, challenging or inaccessible. For example, Amir *et al*. (2007) and Chao *et al*. (2007) utilized the service robots for application in the inspection and maintenance, where it replaces the humans. The crack and the types of sediments inside the pipes had been captured using the camera in the robot had also been developed and investigated by Jong *et al* (2010) and kabeer *et al* (2013). Researchers like Kawaguchi *et al* (1995) also developed mini robot to identify the micro defects in the pipe and also developed robots for identifying the cracks in the pipes of smaller diameters. Micro robots also been developed by Koichi (1999) to inspect the small pipes and to identify the micro defects inside the pipes. An attempt had been made by Kuntze (1998) to extract the information from the surrounding and the reaction based on the situation can be obtained by using the sensors. The main objective of most of the research like Md. Raziq *et al* (2012) is to increase the profit by reducing the cost involved in the process, so many attempt had made to reduce the cost of the pipe line inspection robots. Due globalization and automation, the developed robot should follow a standard in the size, shape and the functionality related aspects and that should be follow the handbook of industrial robotics by Parker *et al* (1998). Also the size and the shape of the robot mainly depend upon the desired work volume.

The work volume can be calculated by doing kinematic analysis and the link mechanism analysis by Rattan (2009). Robin *et al* (2000) and Scholl *et al* (1999) developed to do the special activity and specially developed with improved performance. The inspection of various diameter pipes and the importance of various inner diameters had studied and developed a robot to clean the multi diameter pipes had been done by Shigeo *et al* (1999) and Young *et al* (2010). The major component of the robot is the controller and the manipulator, the design of the manipulator decides the accuracy and the performance of the robot were analyzed by Srushti *et al* (2013). Most of the time, the robot controller board cannot do all the computations such as ANN implementations, etc. So the robot should be controlled by the wireless system and successfully implemented by Yusoff *et al* (2012). Beased on the literature review, various gaps had been identified and the solution methodology is explained in the following sections.

In-Pipe Inspection Robot

Designing of an in-pipe inspection robot is a difficult task as it involves factors like pipe internal diameter, bends, tappers, type of joints, lighting, type of sediments, steerability, turning radius, accuracy of movement, size and shape, flexibility, self sustainability, obstacle avoidance, safety, stability, material, weight, actuation, operations, range, etc. In order to accommodate various pipe diameters, the wheels are attached with the base by spring mechanism. The spring mechanism is used to accommodate various pipe diameters by contracting and expanding the wheel base. Also the mechanism used to exert required pressure on the wall of the pipes, so that the wheel can roll over with greater friction and thereby avoiding slippage.

Motion capability of the developed in-pipe robots includes forward, backward, left and right turn motions. The four wheels of the robot are controlled by separate actuators and the switching on and off combinations will provide the above mentioned movements as required. The autonomous movement of the wheels also helps in overcome the stagnation of robots from sediments and joints. The pipe lines are connected with various types of joints and the joints considered for the experimentation in this research are “L” type, “T” type, “Y” type and Cross “+” type joints apart from unions and couplings. The path selection capability of robot inside a pipe is of utmost importance to perform meaningful and accurate inspection. The movement of the linear joints such as flange, couplings and welded joints can be accommodated by wheel spring mechanism. The ultrasonic sensor and infrared sensor identifies the “L” type joints as obstacle and provide automatic movements to the robot. The movement decision for the remaining joints can be achieved manually using the camera images and the required instructions can be given to the robot through the digital machine using receiver and transmitter mechanism. Even though the robot is designed for the horizontal and vertical movements, experimental results are satisfactory for the horizontal movements and not for the vertical and inclined movements.

Steering mechanism and the turning radius of robot depends on the size of the robot and the wheel turning mechanism. The size of the robot has to be decided based on the placement of the sensors, actuators and the controllers. The robot had been developed to provide a smooth movement without any stuck of robot in the pipe line and can be achieved by providing less turning radius for in-pipe inspection robots. The spring mechanism in the wheels gets compressed on one side and expanded on other side and thereby provides better turning radius for the developed robot. Shape adaptability also considered in this research to move the robot for inspection in the pipe lines with varying diameters such as tapered pipes and stepped pipes. Although, with single robot, it might not be possible to cater all ranges of diameters, but at least a robot can be developed for accomplishing a reasonable range of pipe diameters.

The main objective of the robot is to clean the pipes of circular diameter, but the developed robot has the adoptability for the different cross sections such as rectangular, truncated pyramid, circular, semi-circular and elliptical. Sometimes the improper deposition of the sediments also makes the pipe of various non prismatic shapes. The detection of the deposited sediments and the obstacles depends upon the position of the infrared sensor in the robot and the training rate of artificial neural network. This has been achieved by having the spring mechanism in the wheel base and also in the cleaning arm. The spring mechanism in the cleaning arm also provides the required pressure to the cleaning and compensates the cleaning head wear. The gyroscope sensor in the circuit board sends the signal to the digital machines and is used to control the stability of the robot manually, as the stability of the robot inside the pipeline will play a major role. Any instability or upside down of the robot will lead to difficulty in bringing back the robot from the pipe line. This is again a measure concern particularly with inclined and vertical pipes. So in this research, robot orientation control has been done manually.

Infrared and ultrasonic sensors are used to detect the obstacle and to provide the proper navigation for the robot, in order to make the robot motion and operation automatic. These sensors avoid any collision between robot body with obstacle and wall of pipe lines. Because any damage to the pipe interior will lead to failure of the pipeline. Camera is used to capture the interior images of the pipe line and also to view the status of in-pipe operations. Separate lighting system with LED had provided in the robot to illuminate the interior of the pipe lines, which is easy to interpret the images obtained. The obtained images are transferred to the digital machines for neural network decision making. The developed robot is given in the Figure 1.

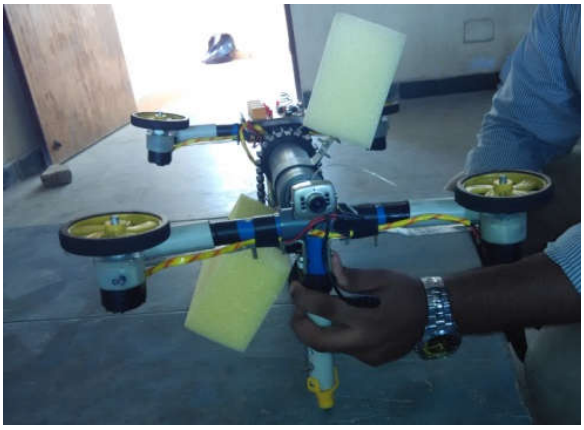

Figure 1. Developed Pipe Cleaning Robot

Vision Intelligent Robot

Vision intelligence can be defined as the acquisition of image data, followed by the processing and interpretation of these data by artificial neural network for some useful decision making.

The use of machine vision and neural network in interior pipe cleaning robots can provide solutions for variety of problems associated with it. Artificial neural network capable of processing number of different pieces of information simultaneously through the interaction of large number of highly interconnected processing elements called neurons. Several ANN models like Adaline and Madaline, Backpropagation, BAM, Hopfield memory, Counterpropagation, etc., are available. Backpropagation has certain advantage over the other algorithms i.e. varying step size, flexible learning speed, any number of stopping criteria can be fixed, network size is user defined, network pruning is easy, etc. In the Backpropagation network (BPN), the activation function chosen is the tan sigmoid function, which compresses the output value in a range between 0 and 1. Tan sigmoid function used is given in the Equation 1.

$$OUTPUT = 1/\,(1 + e^{ai}) \qquad (1)$$

Whereas 'a_i' is the activation function defined as $\Sigma w_{ij} * o_j + t_i$

w_{ij} is the weight value of the link joining i^{th} and j^{th} neuron,

t_i is the threshold value of the neuron.

In the present work, BPN algorithm is used for image processing. First the number of layers and neurons are initialized to 70, 150, 250, 100 and 7 neurons in input, hidden and output layers respectively. Processed image data is given as input along with the expected output data to the network. Weight values and threshold values are obtained by calculations and are stored in the database. Output of the BPN is calculated using the forward propagation. Based on the calculated output, error value is found. Error value is the difference between calculated and desired output. If the error value is greater than the mean square error, then the error is back propagated through the network. During backward propagation the weight and threshold values are updated accordingly. Repeat this procedure until the error value reaches the least minimum. Thus the BPN is trained. After training the network can be implemented for application. For experimentation, fifty different set of images were taken for training and ten images were taken for testing the network. During training phase, the weight matrix, w is updated according to the following formula given by,

$$\Delta w_i\,(n+1) = \eta\,\Big(\sum_{k=1}^{T_{train}} \partial^k{}_w\, O_h\,[j]\Big) / T_{train} + \sigma\,\Delta\, w_i\,(n)$$

$$j = 1,\, 2,\, 3,\, \ldots..n$$

where η is the learning parameter, σ is the constant, T_{train} is the total number of training cases, $O_h\,[j]$ is the output from the j^{th} hidden unit or i^{th} component of k^{th} training vector, and $\partial^k{}_w = (t_k - O_k)\, O_k\,(1 - O_k)$, where t_k and O_k are the desired output and the output of the network for the k^{th} training vector respectively. Table 1 shows the random weights which are initially assigned to **w** and the weights after the back propagation learning for the data set 1 (note: table shows a sample initial and trained weights).

Table 1. Weight values before and after training

(a) Random initial weights w_{1j}					(b) Weight w after The Back propagation Training				
0.7159	0.4665	0.2002	0.2299	0.8857	0.7987	4.306	0.3575	0.9417	0.4486
0.3713	0.4927	0.5810	0.3959	0.39950	0.8303	0.9769	0.3052	0.7698	0.4397
0.9818	0.6434	0.8702	0.2426	0.9047	0.8371	0.8816	0.2501	4.6E-2	0.8009
0.7674	0.0697	0.1794	0.7382	0.5857	0.50827	0.9128	-0.351	0.0143	-7.1E-02
0.9091	2.8E-2	0.3387	0.5911	0.7221	0.4488	0.4374	0.2362	0.3483	0.2647
0.7785	0.2564	0.5689	0.1256	0.2654	0.7856	0.5689	0.9987	0.4257	0.9874
0.8759	0.9689	0.1259	0.5478	0.7521	0.7554	0.2E-01	0.5694	0.6487	0.2532

Experimental Implementation

The developed robot is allowed to move through the interior of the pipes, the springs pushes the wheel away from the robot and make the necessary grip to the robot to move on the inner circumference of the pipe. Then the camera captured the interior of the pipes on-line with the help of LED lighting. The obtained video image had converted to bitmap format which is having the structure as shown in Figure 3. Form the Figure 2, it is clear that the actual image data starts from 54^{th} byte of the bitmap file and to reduce the computational time, the obtained color image need

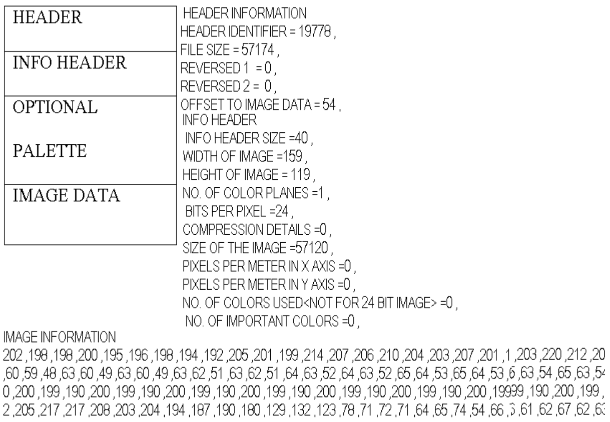

Figure 2. Bitmap file format

to be converted to monochrome image by converting the color intensities into single binary code i.e. either 0 or 1 based on the degree of darkness. This image contains large amount of noises due to various external parameters like orientation, size, illumination, background, etc and that should be filtered. To filter this noise each and every pixel are compared with its surrounding eight pixels. If this pixel and maximum number of the surrounding pixels are different, then the pixel is converted to the surrounding pixel value. The attributes of the camera image is varying due to external factors like focal length, orientation of camera, angle of capturing, etc. Again, the image contains large quantity of raster data. This can be overcome by using SPIHT method of image compression and thereby achieving the compressed image without data loss in shorter time. In this method, the image is divided into four equal quadrants. Again each quadrant is divided into four equal sub quadrants.

This dividing procedure will continue till the image matrix size reaches to the least minimum size i.e. the stage in which further dividing cannot be possible. The image data in that matrix are read. The maximum repeated code might assume as code for that matrix. In this way the size is reduced by $¼^{th}$. Again the same procedure is repeated until the required size obtained and the size of 70 is considered in this research. The compressed image has to be given as input to the trained ANN. The ANN parameters used for the researcher are Mean squared error: 0.01, the total output error $T_{error} = \sum Dop - Oop$, is less than 0.01, maximum number of iteration: 100, Learning rate: 0.3. Thus the trained ANN extracts the required information and generates the output to control the motors for movement and for cleaning and rubbing operations. The same procedure has to be repeated till the robot moves all around the interior of the pipe lines. The same procedure can be used not only to clean the interior of the pipes, but also to identify the cracks, damages and to predict the life time of the pipes.

Conclusion

A real prototype had been fabricated and tested for the robot functionally. The spring mechanism designed has improved the mobility of the robot in pipeline. The control system used consists of two sections, one on the robot to control the movement and to overcome the obstacles on the path and also to identify the joints on the pipe lines. The second section of the control system is on the digital machine to run the image processing module and artificial neural network module which assist the robot for cleaning purpose. These control systems has communicated through one transmitter and another receiver. The robot performance of the robot had been improved by investigating the angular positions of the links, by compressing the image using SPIHT and by conducting sensitivity analysis for identifying the ANN parameters. The experimentation had been conducted for various combinations of pipes with different types of joints and sediments. The obtained results were found satisfactory and the developed intelligent robot can be used for the real time pipe inspection and cleaning.

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