# Review of the State-of-the-art Sewer Monitoring and Maintenance Systems Pune Municipal Corporation - A Case Study

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***Abstract*** **– There is an increasing trend of using automated and robotic systems for the tasks that are hazardous or inconvenient and dirty for humans. Sewers maintenance and cleaning is such a task where robots are already being used for inspection of underground pipes for blockages and damage. This paper reviews the existing robotic systems and various platforms and algorithms along with their capabilities and limitations being discussed. A typical mid-size city in a developing country, Pune, India is selected in order to understand the concerns and identify the requirements for developing robotic systems for the same. It is found that major concern of sewers are blockages but there is not enough information on both real-time detection and removal of it with robotic systems. On-board processing with computer vision algorithms has not been efficiently utilized in terms of performance and determinations for real-world implementations of sewer robotic systems. The review highlights the available methodologies that can be utilized in developing sewer inspection and cleaning robotic systems.**

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## 1. Introduction

Sewers are important part of modern sewerage system that discreetly and safely carry waste and storm water away from the buildings to a treatment place. For the whole system to function securely, sewers have to be in good conditions. Regular maintenance and improvement of sewers are essential responsibilities of authorities that operate the system.

There are many practical causes that lead to early deterioration of the sewers. These include blockages, cracks, joint displacement, tree roots intrusions. Failure of sewer may result in large volume of leakage causing environment risk and public health issues. Sewer blockage is a big concern which causes overflowing of dirty water causing foul smell and health risks to people. Thus, a lot of money and manpower are spent by authorities to ensure proper functionality of sewer systems.

Sewer maintenance and cleaning issues have drawn attention of operators and developers around the world. In developing countries like India blockages have been removed by manual cleaning, which is an undignified method and also harmer health hazard for the persons involved. Thus, mechanical and chemical cleaning methods have replaced manual cleaning. Sewer inspection is an important part of sewer maintenance to identify potential problems and resolve them part of routine maintenance program. Over the time automated and robotic systems were developed. Earlier tele-operated robot platforms were controlled by the human operator and connected by cable with an external energy supply (Stein and Niederehe, 1992). Since then, several improvements were made and robotic systems are now widely available for inspection and cleaning of sewer systems. The robotic systems are a preeminent alternatives for navigation and performing a task in the dull, harmful, and unmanned area.

In this paper, the state-of-the-art review on various automated sewer maintenance and inspection systems is presented and future development needs for automated systems are discussed. A case study of Pune Municipal Corporation (PMC) is considered to highlight the specific requirements for a typical metropolitan city in India.

## 2. Sewerage Systems and Maintenance in India

Indian sewerage system is a huge problem. Traditionally, manual techniques and manual scavenging was used all over India, which used cleaner entering the sewer pipe and septic tanks for cleaning. However, in the last decades the Government of India (GOI) has taken various initiatives to stop hazardous cleaning and to avoid accidents and human casualties during improper practice of cleaning of sewers, septic tanks etc. Only recently the GOI announced measures to end the discriminatory and hazardous practice of manual scavenging by August 2021. Ministry of Housing and Urban Affairs issued Standard Operating Procedure (SOP) For Cleaning of Sewers and Septic Tanks in Nov 2018 [27]. The details for type of inspections and examinations of sewers are provided and recommendations are made for sewer cleaning strategies in the report. However, more funds are required for the organizations responsible for sewerage systems to buy the necessary equipment. Indirect inspection technologies for sewer systems applicable for Indian conditions are identified [27] as shown in Table 1. and Fig.1.

*Table 1. Sewer System Inspection Technologies considered applicable to Indian conditions*

<table>
<tr><th rowspan="2">No</th><th colspan="4">Viability</th></tr>
<tr><th>Technology</th><th>Sewer Material</th><th>Sewer state</th><th>Sewer Dimension</th></tr>
<tr><td>a)</td><td>Sonar Technique</td><td>varying</td><td>Completely carrying</td><td>Varied Dimension</td></tr>
<tr><td>b)</td><td>Technique of Light and Mirror</td><td>varying</td><td>Vacant</td><td>ready for 300 mm</td></tr>
<tr><td>C)</td><td>CCTV</td><td>varying</td><td>Vacant</td><td>Varied Dimension</td></tr>
</table>

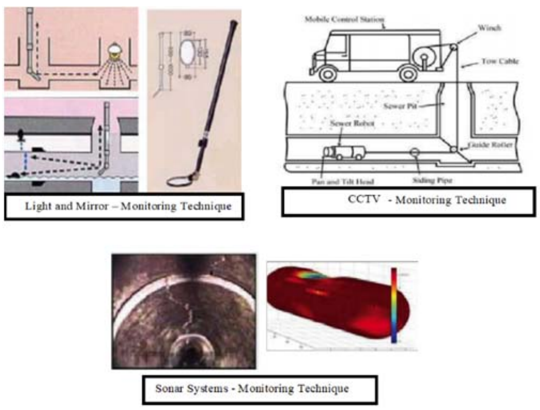


*Figure 1. Sewer Inspection Technologies*

Table 2. shows the cleaning techniques used in Indian conditions as recommended in [27].

### *Case Study - Pune Municipal Corporation*

The first sewer system was constructed in Pune city in 1928. This system was designed for 31.8 MLD to cater to the ultimate design capacity for population of 0.26 million in the year 1951. Population of the city grew to 7.4 million in 2020. To date, there are 11 sewerage treatment plants (STP) that process 396 MLD in the city. A survey was conducted to assess the current provisions for treating sewerage in the city and issues relating to operating of the system. Table 3. shows the basic data and available tools in the municipality for maintaining sewers pipes.

*Table 2. Sewer Cleaning Techniques*

<table>
<tr><th colspan="4">Sewer cleaning Techniques</th></tr>
<tr><td rowspan="6">Labour-intensive Practices</td><td rowspan="3">Cloth Ball and Manila Rope</td><td rowspan="6">Automated Practices</td><td>Gully Emptier</td></tr>
<tr><td>Hydraulically Driven Tactics</td></tr>
<tr><td>Bucket Machine</td></tr>
<tr><td>A collected wood board - Scraper</td><td>Rodding Machine with Flexible Sewer Rods</td></tr>
<tr><td rowspan="2">Sectional Rods for Sewer</td><td>Speedy cleaners (Jetting Machines)</td></tr>
<tr><td>Dredger (Clam-shell)</td></tr>
</table>

*Table 3. PMC Surveyed Data*

| Terms | Details |
|---|---|
| Sewer Line | 2167 kilometre |
| Sewer Pipe Diameter | Ranges from 100 mm to 1800 mm |
| Total Chambers (manhole) | 2187 |
| Sewer Pipe Material | ▪ RCC<br>▪ High-density polyethylene (HDPE)<br>▪ bid-iron<br>▪ PVC |
| Distance Between Chambers | 10 to 15 meters |
| Sewer Net pressure | 1 to 4 |
| Sewer Cleaning Techniques | ▪ Suction Cum Jetting Machine with a Recycler<br>▪ Suction Cum Jetting Machine<br>▪ Jetting Machine |
| Total Generated Sewage | 744 MLD |
| Intermediate pump stations (IPS) | 6 |
| Sewage Treatment Plants (STPs) | 9 |
| Main Sewer Lines | ▪ Below road<br>▪ River side<br>▪ Canal side |
| ***Cleaning Tools*** | ***Charges/Shift (8 hours shift)*** |
| ▪ Suction Cum Jetting Machine | 6400 INR |
| ▪ Suction Cum Jetting Machine with a Recycler | 37000 INR |
| ▪ Jetting Machine | 5360 INR |

Figure 2. shows some of the real incidents of cleaning operation in the city.

It is evident that the mechanical cleaning is mainly used. During interviews with the officials, it was revealed that their goal of maintenance of the sewers is to reduce the number of sewer blockages per unit length. Therefore, inspection and scheduled cleaning is very important part of sewer maintenance. The PMC tries to follow recommended government guidelines for regular inspection and cleaning of the sewers but reliable techniques and tools are not available.

*Figure 2. Visible outturns at PMC survey site*

There are several GOI schemes to upgrade the technology for cleaning sewers across India, the PMC officials informed that due to budget restraints they do not have adequate tools.

Existing machines use suction method and jetting to carry dirt out of sewers and pure pipes with lofty-pressure jets of water. At places mainly in densely populated areas, the machines are often too big to enter some narrow streets sometimes cleaning is manually performed. In such scenarios small and portable robotic system would be ideal.

The robotic systems also have cameras for locating the blockages and help the cleaning arm navigate toward it. In the next section advances in the robotic system are discussed.

## 3. Features of Various Robotic & Automated Systems

Robotic systems are classified as no-autonomy, semi-autonomy, and full-autonomy and are capable for detecting and measuring damage and cleaning. The CCTV (Closed Circuit Television), SSET (Sewer Scanner and Evaluation Technology), Laser Scanning are different techniques which are used for sewer pipe inspection. Also, the computer vision is extending its power with AI revolution on embedded platform.

Many sewer robotic systems such as PIRAT, KARO, KURT, MAKRO, KANTARO, and SIAR are reported by many researchers as explained in the following sections.

Kirkham et al. [1] developed PIRAT (Pipe Inspection Real-Time Assessment Technique) sewer inspection semi-autonomous tethered system that could evaluate the physical data using some interpretation technique. AI techniques were developed system to find out and categorize damages using the three-dimensional model data. A human operator had to find out real damages, as well as the damaged regions in the images marked manually. The system is a decade old with employed algorithms, and the performance parameters are poor.

Kuntz et al. [2] presented tethered, semi-autonomous KARO (KAnalRoboter) sewer inspection equipment which was capable for auto-correction of tilting pose and slippage in wheel. Pipe bends, larger cracks in pipe, and obstacles within the pipe were identified by a 3D optical sensor and a microwave sensor. This means that the robotic system was mostly dependent on sensors and read data.

The PIRAT and KARO both had main control routines on a computer in the movable control unit and did not comprise on-board hardware.

Kirchner and Hertzberg progressed six-wheeled, untethered KURT (Kanal–Untersuchungs–Roboter-Testplatform) for autonomous navigation in a dry sewers test net in [3]. KURT1 was competent to classify a pipe junction type and this patented method was complimented as probabilistic mapping of objects, similar to sewer landmarks. The new KURT2 included sensors for odometry and in-clinometers, ultrasound distance or infrared transducers for obstacle detection, and optional bumpers. In this, sensors may not work in a real sewer pipe due to dirt covering. Also, ultrasound sensors are too large in size. The overall reliability of this robotic system is sensor dependent and only inspects the sewers and has no ability to solve issues. Rome et al. [4] came up with an untethered, self-steering MAKRO (Mehrsegmentiger Autonomer KanalROboter) robot for fully autonomous navigation in roughly cleaned sewer pipes. It carried all resources on-board. In this, the ultrasound range sensor was exploited to detect obstacles that block the pipe. All tasks such as collision avoidance, movement control, obstacle detection, and landmark detection were done by the sensors. The computer vision algorithm or methodology was not clearly present and focused only on applications of sensors.

Nassiraei et al. developed KANTARO, a fully autonomous, un-tethered, passive-active intelligent robot having intelligent modular architecture involved in mechanism and sensor [5]. They also proposed a small and smart 2D laser scanner for directional landmarks detection and utilized the fish eye camera to assess pipe condition and defect detection. They proposed a horizontal and vertical similarity approach for automated faults detection in sewer pipes using images. In this work, the accuracy of faults detection software was not high enough as needed. Alejo et al. introduced SIAR (Sewer Inspection Autonomous Robot), a system that can detect critical structural defects in sewer pipelines by employing 3D structure reconstruction in real-time and also take water or gas samples of the environment for further analysis [6]. This robotic system comprises RGB-D sensors with a powerful wireless communication system.

Abidin developed an in-pipe robot for cleaning soft and moderate clog [7]. The ultrasonic sensor was used to detect diameter difference that means if the detected diameter is small then it will be considered that blockages are present inside the pipe. In this, the cleaning operation was performed when the detected distance is less than 30mm. This system was not capable to remove stubborn clog. The development was lab scale based on very basic experiment and there was not waterproofing feature for real-time application.

Vaani et al. [8] developed an automated sewer robot named as BhrtyArtana where 'Bhrtya' stands for robot and 'Artana'; stands for waste. This robot was capable of inspecting cracks, corrosion, and obstacles as well as clearing any blockage within it. A camera was installed to get real-time video feed for analysis and a proximity sensor was connected to detect obstacle in front of it so that the turbine will start cutting and clearing the obstacle. The implemented prototype did not have intelligence of automated defect detection feature. It is sensor dependent for obstacle detection.

Gobinath and Malathi implemented a Machine Robot having a Robot-Arm [9]. That Robot-Arm was utilized by a few Axis with Stepper Motor to progress with distinct angles from left to right and then from top to bottom. An LCD was used to display the sewage cleaning process. In this, toxic gases were detected by a board of SewerSnort gas sensor with a MicaZ mote. The developed system does not comprise camera-based automated defect detection and depends on the sensory network. It is costly and needs modification for the real-world prototype.

Prasad and Karthikeyan executed a robot for cleaning and removing the blockage in large sewer pipes [10]. The blockages were detected by ultrasonic sensors and cleaned by a drilling mechanism. A MATLAB tool was used for monitoring video and captured images from a wireless camera. The developed mechanism was not advanced and did not utilize computer vision excepting video feed from the camera.

Abro et al. conferred an autonomous sewerbot that detected the defects in sewerage pipelines as well as blockages using digital image processing [11]. They also investigated the attributes of a specific sewerage line utilizing IoT. The gradient and segmentation techniques were applied for sewer pipe blockage detection with a wireless camera. Overall, they tried to solve all inspection issues but the developed algorithm and performance were inferior for real-world implementation. Table 4. shows the confines and respective remarks for the illustrated robotic artifices.

*Table 4. Implemented robotic artifices with their confines and remarks*

| Robotic Artifices | Confines and Remarks | Ref. No. |
|---|---|---|
| PIRAT | No main control routines onboard and reliability depends on human operator | [1] |
| KARO | Reliability depends on human operator and fully sensory data | [2] |
| KURT | Fully sensory system and sometimes do not work due to environmental aspects | [3] |
| MAKRO | Lack of efficient Computer vision methodology and focused only on sensors applications. No ability to move inside of bending pipe. | [4] |
| KANTARO | Low accuracy of faults detection software, absence of methodical approach to amend practically | [5] |
| SIAR | Advanced system but having no ability to clear and reform pipe condition in real-time | [6] |
| In-pipe Robot | Very basic prototype and cannot be accessed for real-time applications. | [7] |
| BhrtyArtana | No efficient methodology for defect detection and removal for real-time applications | [8] |
| Machine Robot | Very costly and needs modification in comprised techniques for the real-world prototype | [9] |
| MATLAB Based Robot | Poor computer vision technique | [10] |
| Sewerbot | The algorithm and performance were inferior for real-world implementation | [11] |

The key differences between types of sewer robotic systems have been depicted in depth in the following Table 5.

*Table 5. Differences between types of sewer robotic systems*

| No-autonomy | Semi-autonomy | Full-autonomy |
|---|---|---|
| entirely teleoperated | teleoperated with some amount of self-intelligence | full intelligence for self-navigation |
| tethered | may be tethered or un-tethered | un-tethered |
| assessment reliability depends on human operator | assessment reliability depends on both human operator and system intelligence | assessment reliability depends on system intelligence |
| less sensory system and simply driven by human operator | involve moderate sensors with moving assembly | comprises several sensors and critical moving assembly |
| fine in small diameter pipes | preferable in small diameter pipes | not trustworthy in small diameter pipes |
| control unit at remote location | may fetch all obligatory resources onboard or control unit may be at remote location. | fetches all obligatory resources onboard |

The robots working in the pipes are categorized depending on their moving techniques as shown in Figure 3.

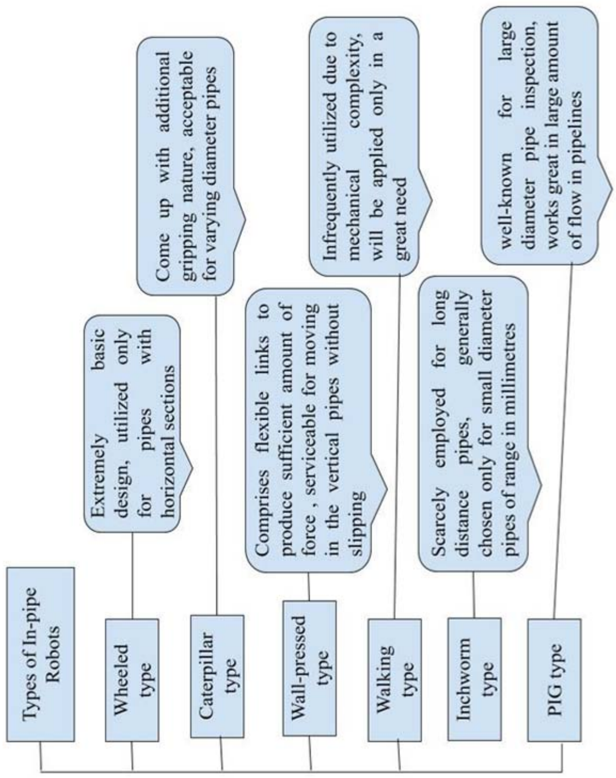


*Figure 3. Categorizations of robots based on moving techniques*

## 4. Initiated Computer Vision Algorithms and Perusal

Here, some identified methodologies are discussed for their influence and limitations. Kumar and Abraham made a contribution of the framework that applies Deep Convolution Neural Networks (CNNs) to classify various issues such as root intrusions, cracks, and deposits in sewer CCTV frames [12]. They trained and assessed CNNs using 12,000 frames gathered from over 200 pipelines for accuracy, precision, and recall. It is observed that generated consequences are from images and not from real-time navigation and various defects have been classified and not detected with locations.

Cheng and Wang initiated an automated approach for identification of sewer pipe faults centred on faster R-CNN [13]. In this, 3000 images of sewer pipes captured from CCTV inspection videos were applied for training the detection model. Then the model was analysed for detection accuracy and calculation cost by consuming missing rate, mean average precision (MAP), training time, and detection speed. This approach only functions for standing frames and not for the real-time video feed. It also consists of a few incorrect classifications for cracks in the experiments. Gutiérrez-Mondragón et al. originated a technique to train a Convolutional Neural Network for detecting the obstruction level in pipes [14]. By gathering video database from CCTV, they generated useful frames to train the model. They integrated the Layerwise Relevance Propagation explainability technique for understanding the neural network behaviour for this task. It has been predicted that the proposed system can provide greater accuracy, speed, and consistency for sewer examination in real-time. This work only focused on the quantity of obstruction in the sewers and not on type and locations.

Halfawy and Hengmeechai mentioned a methodical algorithm of HOG (histograms of oriented gradients) and SVM (support vector machine) to find tree root intrusions' defects in images collected from conventional CCTV inspection videos [15]. This was two steps processed as: (1) image segmentation to extract regions of interest (ROI) showing defect areas and (2) classification of the ROI using SVM classifier trained by the HOG features. Here, the algorithm was applied only on static images and not on a video sequence and larger data sets. Yin et al. proposed a framework for real-time automated defect detection in sewer pipe by using the CNN based YOLOv3 object detector [16]. The model had been trained with a data set of 4056 images that includes six types of defects such as broken, hole, deposits, crack, fracture, and root and one type of construction feature tap. The proposed model had not been tested in real-time in the sewer pipe and it needs some improvisation in performance parameters.

Moradi et al. presented an automated sewer pipeline inspection and condition assessment method using computer vision techniques [17]. In this, a region of interest (ROI) of sewer defects was identified first and then classification was done on frames. The hidden Markov models (HMM) had been used to extract frames from sewer CCTV videos and CNN was proposed to detect the defects and classify them. This work was also based on dataset testing with average results.

Kumar et al. evaluated a deep learning-based framework such as single-shot detector (SSD), you only look once (YOLO), and faster region-based convolutional neural network (Faster R-CNN) for speed and accuracy in classifying and localizing root intrusions and deposits in sewer CCTV images [18]. For training and testing of the models, 3800 annotated images of defects were used. Here, the Faster R-CNN model had the highest accuracy for defects detection and the slowest speed for processing each image. The YOLOv3 model presented a slightly lower accuracy than the Faster R-CNN and was nearly twice as fast as the Faster R-CNN to treat every frame. The SSD model appeared to have the lowest accuracy but the highest speed to process each image. On average in this research, the incorporated dataset of training and testing was very little to attain expected consequences. Also, there is a need to enhance the speed and accuracy of the prototype.

## 5. Review of Earlier Surveys

Haurum and Moeslund surveyed the last 25 years of research for sewer inspection. They presented a detailed outline inside the field of image-based automation of Closed-Circuit Television (CCTV) and Sewer Scanner and Evaluation Technology (SSET) for sewer inspection [19]. A review was also performed of the pipeline algorithmic, and datasets and protocols. Authors investigated all aspects of automated inspection pipeline such as image acquisition, preprocessing, detection and segmentation, feature description, classification, and temporal filtering. From the survey, it is suggested that free and publicly available datasets should be created, should have open-source code for each publication and standardized evaluation metrics. Moradi et al. reviewed the current state of sewer pipeline inspection technology associated with computer vision and machine learning techniques [20]. The assessment compared advantages and disadvantages of one and all methods. The image preprocessing, Image representation and Learning have been deeply examined for defect detection in sewer pipe. In this, it is highlighted that CCTV cameras must be standard, must have influential hardware with lofty specifications as well as standard dataset and robust algorithms.

Liu and Kleiner explored the techniques for pipe inspection and for assessing the condition of water distribution and transmission pipes [21]. In their paper they also discuss various technologies such as smart pipe, augmented reality, and intelligent robots and scrutinized for their performance and real-word relevance. They also shed light on the significance of the CCTV and laser scanning techniques. Tur and Garthwaite reviewed existing robotic tools and noticed unclick problems for development of a successful robotic sewer pipe inspection device [22]. Types and mechanisms of robotic systems, acquired sensing technology, and the CCTV and SSET techniques for visual perceptions have been highlighted. They discussed principal affairs of communication, data management, and energy sources. The robots should be implemented for performing specific tasks so that these robotic systems will be cheap and will consume less energy to move.

Czimmermann et al. focused on automated visual-based defect detection methods appropriate to materials such as metals, ceramics and textiles [23]. They pointed to two types of defects such as visible and palpable. They also described acutely artificial visual processing techniques, supervised and non-supervised classifiers and deep learning algorithms for detection and classification of defects. It is noticed that the inadequate test samples, mostly incompatible database, and not developed concrete algorithms are the issues for a perfect inspection system.

Following are the common sewer affairs that are considered in earlier research papers as shown in Figure 4.

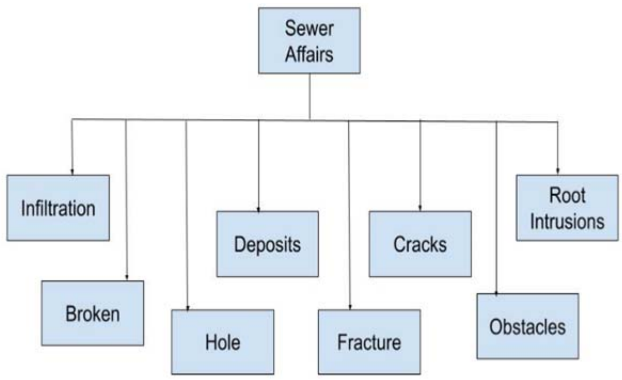


*Figure 4. Appeared sewer affairs in the research work*

Out of all these sewers issues, sewer blockages are the major issues. Significant causes of sewers blockages due to accumulated debris are identified as follows –

- sand
- silt (i.e., sludge)
- plastic
- grease
- roots and leaves
- rocks
- toiletries waste (such as clip on toilet freshener holders)
- foreign objects such as baby diapers and wipes, tampons, oil, sanitary napkins, cat litter, cotton balls, hair, children's toys etc.

There is no reliable general algorithm and robotic system formulated for both identification and removal of different sewer blockages in real-world scenario.

## 6. Sewer Monitoring Techniques

### *A. Modern computer vision techniques*

The most of the area of computer vision is untouchable by the AI techniques. This area comprises intelligent algorithms to return evocative information from frames and videos. These conventional computer vision algorithms are enough to produce admissible output for lower imagery data but outcomes of these algorithms get saturated for larger datasets. At this point, machine learning and deep learning techniques confer sublime outturns. The machine learning techniques are handcrafted algorithms whereas deep learning techniques use deep neural networks for solving classification and regression problems. The deep leaning models need a large number of images for enhancement in accuracy [28]. The features selection and training platforms are also an important aspect in object detection and classification tasks [29], [30]. The precision rate and efficiency of these AI techniques depend on the quality of imagery data.

In below Figures 5. and 6., the general mechanism in machine learning and in deep learning strategies have been depicted for identification of sewer affairs.

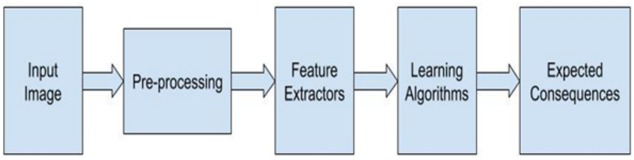


*Figure 5. Mechanism in Machine learning strategy*

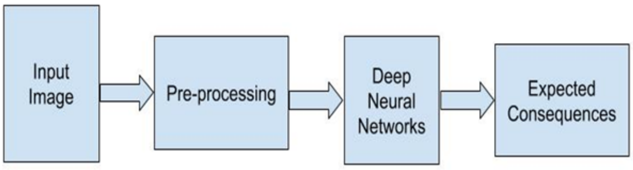


*Figure 6. Mechanism in Deep learning strategy*

In Table 6., the acquired methodologies in object detection tasks have been listed due to their significance and involvement in the earlier research work.

*Table 6. Crucial methodologies*

| | |
|---|---|
| **Conventional Algorithms for pre-processing and detection task in Computer Vision** | ▪ Colour spaces<br>▪ Image stitching, mosaicking, and unwrapping<br>▪ Thresholding<br>▪ Noise removing<br>▪ Morphological operations<br>▪ Image enhancement and filtering<br>▪ Geometric transformations etc. |
| **Learning and Classification Techniques in Machine Learning** | ▪ SVM<br>▪ k-means<br>▪ k-NN<br>▪ Decision Trees<br>▪ Logistic Regression<br>▪ Random Forests<br>▪ Naïve Bayes |
| **Deep Learning based object detection modules** | ▪ SSD VVG<br>▪ YOLOv3<br>▪ Faster-RCNN<br>▪ Tiny YOLOv2 |
| **Classifiers in Deep Learning** | ▪ GoogleNet<br>▪ AlexNet<br>▪ CaffeNet<br>▪ ResNet – 18v1, ResNet – 50v1<br>▪ ZFNet 512<br>▪ MobileNet v2<br>▪ SqueezNet<br>▪ ShuffleNet<br>▪ DenseNet 121<br>▪ CNN Mnist |
| **Segmentation Deep Neural Network Modules** | ▪ Mask R-CNN<br>▪ FCN<br>▪ ResNet 101_DUC_HDC<br>▪ ENet |

The robotic systems need to be energy efficient and cost effective for realistic applications and it depends on selection process of finest hardware and software combinations [24]. In this, the embedded platform is the foremost optative with computer vision methodologies for real-world visual implementations [25], [26]. So, embedded vision is a spacious area of research for pragmatic evolution in diverse fields.

## 7. Conclusion

In this review, the existing sewer robotic systems are analysed for features, resorted frameworks and mechanisms. Overall, it is concluded that the sewers blockages are the predominant issues of buried infrastructure. The earlier and modern techniques for unblocking sewers are discussed with particular reference to the PMC cleaning and maintaining techniques of the sewer infrastructure.

The review of published research results revealed that computer vision algorithms with on-board processing are not efficiently utilized. To the authors' knowledge, no robust algorithm and robotic system available for both real-time detection and removal of sewer pipe blockages exists to date. This presents a research opportunity to develop such algorithm that may be integrated with existing or newer robotic systems for inspecting and cleaning of sewer systems.

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