Application of Robotics for a Social Cause in India

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Abstract: ***India's waste management debacle has resulted in clogged landfills, pollution and severe health hazards, worsened by inefficient and hazardous manual waste collection. Despite government efforts, sanitation workers continue to face dangerous working conditions, necessitating a need for innovative solutions. This paper discusses the creation of a remote-controlled robot designed to clean roadside gutters and sewers, minimizing risk of infection for manual workers by minimizing exposure to harmful waste while improving efficiency. By integrating robotics into sanitation efforts, this system improves public health, environmental protection and the overall waste management. With a scalable and cost-effective design, it paves the way for future development in automated waste disposal across India.***

Keywords: Robot, Gutter cleaning, social cause, India

1. Introduction

India is home to over 1.4 billion people and is facing a serious challenge with its urban infrastructure, especially drainage systems. This problem has grown worse in cities that are rapidly expanding, bringing more people into crowded spaces with inadequate systems to handle waste. The United Nations predicts that "India will contribute most to the urban increment with the addition of 416 million urban dwellers, nearly doubling the size of its urban population between 2018 and 2050" (UN DESA 2019). When drainage systems are overwhelmed, especially during the monsoon season, it leads to flooding, waterlogging and water stagnation, which can quickly become breeding grounds for diseases transmitted by mosquitoes like malaria and dengue. The Indian Council of Medical Research (ICMR) reports that there are millions of dengue cases every year making it a major public health concern (ICMR 2022). The rapid pace of urbanization in India has made it difficult for the country to improve its infrastructure fast enough to keep up with the growing population. Many cities are struggling to provide proper drainage leading to flooding on roads (figure 1). This lack of infrastructure creates serious health problems. In areas with poor drainage, stagnant water leads to the spread of diseases. Treating these illnesses, such as dengue, can be costly for families. On average, dengue treatment costs can reach $35(₹3,000) which is a huge amount for low-income families (ICMR 2022). Poverty in India is another major factor that affects how well people can deal with these drainage issues. The World Bank estimated that about 12.9% of India's population lived below the international poverty line of $2.15 a day (around ₹180) in 2021 (World Bank 2021). Living in poverty often means limited access to proper housing and sanitation. In low-income neighbourhoods, blocked drains and flooding are common, making living conditions even more difficult. People living in these areas might earn less than ₹10,000 per month, and even a minor flood can cause damage to their homes that is expensive to fix. Proper drainage infrastructure can help lift the burden on these families, improving both their health and financial stability. Homelessness is a significant issue in Indian cities. The Press Information Bureau reported that around 1.77 million people were homeless in 2021, however, the real number is likely to be higher due to increasing urban migration (PIB 2021). People living on the streets are especially vulnerable when it comes to poor drainage, as they often sleep near open drains or flood-prone areas. This exposes them to various health risks, like respiratory infections and skin diseases. Healthcare for the homeless can cost anywhere from $5 to $20 (₹500 to ₹1,500) for common infections, which is unaffordable for most of them. To address the drainage problem, India needs large-scale efforts from both the government and local communities. The government has started projects such as the Swachh Bharat Mission to improve sanitation and hygiene in India (Swachh Bharat Mission 2014). However, this is not enough. The World Bank estimates that India will need to invest over $840 billion (around ₹70 trillion) in infrastructure by 2036 to meet the growing demand (World Bank 2021).

Figure 1: Residents of a slum sit outside their homes along a sewage canal after water levels increased following a monsoon rainfall in New Delhi. (Photo: AFP)

Waste management in India is a problem that affects not only urban centres but also rural regions. With over 100 million tons of waste generated annually, Indian cities are facing a garbage crisis despite the Supreme Court's directives for comprehensive waste management programs ref. These programs, which should include segregated waste collection, recycling, and composting, have largely been ignored by municipal authorities ref. The result is unchecked pollution and public health hazards (Khandare 2018). Furthermore, the Swachh Bharat Abhiyan, which allocates substantial resources to cleaning up India, has not fully addressed the waste crisis due to inadequate implementation at the local level. Municipal Solid Waste Workers (MSWWs) are on the front lines of this crisis, facing considerable health risks as they collect waste without sufficient protection. Exposure to hazardous materials, respiratory issues, musculoskeletal problems, and other occupational hazards are common among these workers, further highlighting the need for safer and more efficient waste management systems (Khandare 2018). With increasing populations and modern living demands, managing waste effectively is becoming more critical. Waste needs to be sorted into categories to streamline processing, and automating this process can also address safety concerns for waste collectors. Recent advancements in robotic waste management focus on enhancing efficiency and ensuring worker safety through the integration of automated sorting and collection systems.

Automated robots are increasingly used in waste management to make the job easier and safer (Gupta 2021). One such example is the Gar-Bot. Gar-Bot successfully sorted and collected garbage with 90% accuracy. It was able to handle garbage weighing up to 400 grams and worked efficiently within its design limits. The robot's performance met the goals set for its prototype stage. Technological advancements such as Gar-Bot illustrate the potential of automation; however, Maurya (2018) emphasizes the ongoing problem of manual scavenging, which remains a threat to workers despite existing legal prohibitions. Future improvements for Gar-Bot include increasing its capacity to handle up to 1 kg of waste, enhancing its ability to detect more complex scenes, and expanding its functionality to sort a greater variety of garbage types. The aim is to develop Gar-Bot into a fully autonomous waste management system with even more societal benefits (Gupta 2021). The issue of manual scavenging continues to persist in India despite legal prohibitions, posing severe health and social risks to sanitation workers (Maurya 2018). The hazardous practice of manual waste removal exposes workers to infections affecting their respiratory, gastrointestinal, and skin health, highlighting the urgent need for technological interventions (Narasimhulu et al. 2023). Various studies have emphasized that caste-based discrimination and socio-economic marginalization force Dalits into this degrading occupation, reinforcing systemic inequality (Maurya 2018). The Swachh Bharat Abhiyan aimed to eliminate manual scavenging, yet implementation gaps remain, and many municipal bodies still rely on human labor for sewer maintenance (Maurya 2018). Researchers have proposed robotic and automated solutions for sewer cleaning and maintenance to minimize human involvement in hazardous waste removal, thereby addressing health risks and inefficiencies. Narasimhulu et al. (2023) propose a *Robotic Clog Remover Vehicle*, designed to mechanize sewer cleaning and reduce health hazards. This device integrates a lifting mechanism, bucket tilting, and motorized travel, enabling efficient waste removal without direct human contact (Narasimhulu et al. 2023).

Waste management is a pressing global issue, and it requires urgent attention, particularly in countries like Pakistan where improper waste disposal poses threats to public health, hygiene, and wildlife safety (Khan, 2020). Both rural and urban areas face a lack of effective waste management systems. Currently, waste collection is mostly done manually, which, while offering employment opportunities, comes with several challenges ref. These challenges include labour shortages on certain days and health risks associated with exposure to harmful materials. Moreover, manual garbage collection is not efficient enough to deal with the increasing waste production and the various health hazards it causes (Khan 2020). One potential solution to these problems is the use of autonomous or semi-autonomous robots for waste collection. These robots can work more efficiently than humans, addressing labour shortages, safety issues, and environmental concerns (Ullah, 2020). Although the initial manufacturing costs of such robots are high, their maintenance costs are low, and they can be more efficient by replacing multiple human workers (Islam, 2016). However, the primary obstacle to widespread adoption is the high production cost, which makes it difficult to implement on a large scale. There is a need to develop cost-effective robotic solutions that can be deployed by government bodies and organizations on a larger scale (Khan 2020). The design optimization of excavator arms plays a crucial role in improving their efficiency, durability, and performance under varying load conditions. (Khan et al., 2016) conducted a detailed investigation into reducing the weight of excavator arms while maintaining structural integrity through finite element analysis (FEA) using ANSYS. Their study demonstrated that modifying the arm's design and changing its material could significantly reduce weight without exceeding safe stress limits (Islam, 2016). Previous research has explored various optimization techniques, including kinematic analysis (Islam et al., 2016), fatigue analysis , and alternative material selection such as aluminum alloys (Hossain, 2016). Additionally, studies on FEA applications in excavator components have highlighted its effectiveness in stress evaluation, fatigue prediction, and weight optimization (Khan et al., 2016). The findings of (Khan et al. 2016) reinforce that systematic modifications in thickness, shape, and material composition can enhance excavator arm performance while maintaining safety standards. Several researchers have explored different methods of automating waste collection. One notable effort is the design of a beach-cleaning robot that uses wireless communication for control. This robot is equipped with a shovel for scooping waste, a trash box for collecting it, and a solar panel to provide sustainable energy (Hammad Khan 2020). The robot also features an IP camera for live video feedback and a Bluetooth module for communication. While the robot is not fully autonomous and is manually controlled by the user, it is designed for use on beaches and other challenging environments. Its eco-friendly design, using solar energy and tank wheels for mobility, makes it a viable option for cleaning difficult terrains, (Hammad Khan 2020). Khandare (2018), proposed a robotic solution that offers a technologically advanced approach to tackling waste collection. Using a Raspberry Pi-3B as the control hub, the robot can autonomously navigate its environment with the help of ultrasonic and infrared sensors. These sensors, combined with image processing technologies like YOLO and SSD, enable the robot to distinguish between living creatures and garbage, ensuring the safety of animals while efficiently collecting waste. The robot's arm mechanism is designed for versatility, allowing it to pick up items such as juice cartons and crushed paper, which are then deposited into a bin for later disposal. Solar power further enhances the sustainability of this system, reducing reliance on conventional power sources and contributing to environmental conservation. With a sturdy metal frame, multiple motors for movement, and a detailed control algorithm, the robot is designed to operate reliably in real-world conditions.

An illustration of an Arduino-controlled robotic system is the robotic arm developed by Ali et al. (2022), showing how microcontroller-based automation at a low cost is effective. The study portrays the design and implementation of a remote-controlled six degrees-of-freedom robotic arm through a Bluetooth-connected mobile application (Al-Sakkal, 2022). The robotic arm has five revolute joints and a gripper. Motion is supplied by servomotors. The mechanical part was modeled in SolidWorks and subsequently manufactured; hence the design allows for precise control and modular assembly. The authors outlined how such robotic arms can improve efficiency at work in industrial automation, specifically where human involvement in potentially dangerous environmental situations such as radioactive material handling or deep-sea and space applications is cumbersome. The study also describes the incorporation of forward and inverse kinematics to achieve accurate movement and control which is crucial for robotic design. An Arduino controlled system fosters the wireless operation of the robotic arm, thus providing a useful model for automation in the wide field of waste disposal robotics. This robotic arm was modular and scalable in character, converging towards the development of autonomous systems that minimize human risk and improve performance in intricate environments (Ali et al., 2022).

The study by Muthugala et al. (2021) presents Raptor, an innovative drain inspection robot designed to overcome the limitations of existing systems in terms of adaptability, maneuverability, and autonomy in confined and uneven drain environments. Raptor incorporates a manually reconfigurable wheel axle mechanism, enabling adjustments to ground clearance (7 cm for "Tuck-In" and 11 cm for "Tuck-Out") to accommodate varying drain dimensions and terrain conditions. A fuzzy logic controller is integrated to autonomously maintain the robot's position in the center of the drain by processing LiDAR-based clearance measurements, ensuring safe navigation and effective inspection coverage. Experimental validation in diverse drain scenarios, including flat, curved, and angled drains, demonstrated Raptor's ability to recover from offsets and heading errors while maintaining an average root mean squared error (RMSE) of 6.6 cm from the drain center. The robot's lightweight, compact design, combined with its reconfigurability and autonomous navigation capabilities, highlights its potential to enhance the productivity and safety of drain inspections. Future research directions include testing in water-flowing drains and exploring multi-robot coordination for improved inspection efficiency (Muthugala et al., 2021). The development of an Automatic Drainage Cleaning System (ADCS) represents a significant advancement in managing waste in urban drainage systems. Conventional methods of cleaning drainage rely on human labour, which poses serious health risks due to potential exposure to harmful waste and chemicals (Ankur Singh 2019). The ADCS introduces a mechanized solution that reduces human involvement and provides a more efficient and hygienic approach to drain cleaning. The ADCS machine operates mechanically using several components such as DC motors, chains, sprockets, and a waste lifter attached to a screen. As water flows through drainage systems, it often carries impurities like plastic bottles, polythene, and other solid waste. These impurities cause blockages, particularly during rainy seasons, leading to overflow and public health hazards. The ADCS is designed to lift and filter out these impurities from drainage systems, thereby eliminating blockages and reducing overflow risks (Ajay Sharma 2019; IJERT, 2019). The system functions by placing the ADCS across a drain. The device uses a screen to allow only water to pass through while collecting floating waste. The screen is connected to a shaft powered by a DC motor through a chain mechanism. As the motor rotates, the waste is lifted by the lifter attached to the screen. The collected waste is then transferred to a horizontal screening mechanism and stored in a container for disposal (IJERT, 2019). The system offers several advantages, including easy maintenance, reduced labour, and a compact, portable design (IJERT, 2019; Mahipal Singh). The ADCS can be applied in various settings, including sewage cleaning, river cleaning, and drainage systems of different sizes. The system's potential benefits extend beyond just solving drainage issues; it aligns with public health and sanitation goals. Addressing drainage blockage issues automatically reduces the risk of disease transmission due to sewage overflow and supports government cleanliness initiatives (IJERT, 2019). Future developments in ADCS technology aim to further enhance its efficiency and applicability. Researchers and engineers are working on fabricating improved ADCS systems and testing their performance in various settings.

Hudy et al., (2021), explored the integration of information technology in science and industry, highlighting its role in improving data collection, experimentation, and analysis. This technological advancement enhances the accuracy and reliability of scientific research and accelerates task execution in industry, improving engineers' technical skills. The paper focuses on the rapidly evolving field of robotics, where advancements in electronics and microprocessors have led to the development of innovative devices combining mechanical structures, electronics, and software. Modern robots, with their mobility and remote control capabilities, are used in various commercial and scientific applications, performing tasks previously deemed impossible. They presented the design and development of a gutter-cleaning robot, intended to automate the hazardous task of cleaning gutters. The robot uses a caterpillar track system for enhanced mobility within the gutter and is equipped with mechanical tools to remove debris. The design process involved CAD modelling, 3D printing, and microcontroller programming, with the nRF24L01 radio module facilitating communication between the robot's components. The power system includes a rechargeable battery and a voltage converter to power the microcontroller and radio module, while the control system is based on an Arduino Uno. Experimental tests confirmed the robot's effectiveness in cleaning gutters, and the paper suggests potential improvements, such as adding a camera for better visibility and more powerful motors. The importance of incorporating such projects into education is emphasized by ensuring that they help students develop essential skills in programming, electronics, and problem-solving. By engaging in practical, goal-oriented projects like the gutter-cleaning robot, students become better prepared to navigate the technological challenges of the future, making them more adept at functioning in an increasingly information-driven society (Stanislaw Gumula 2019). Gutter cleaning robots, like the iRobot Looj 330, represent a niche application of robotics designed to automate the often hazardous and labour-intensive task of cleaning gutters. These devices are equipped with treads and are remotely controlled, allowing them to traverse the length of a gutter to remove debris such as leaves and dirt. The Looj 330, produced by the same company that created the Roomba, was the only commercially available model before it was discontinued in 2017 (Hudy et al., 2021). The operational mechanism of the Looj 330 centres on an auger equipped with soft spinning blades designed to break up and push debris out of the gutter, while bristles at the back sweep up any remaining particles. The device is intended to be easy to use, with different sizes provided to clean various gutter dimensions. Despite its innovative design, the Looj 330 faced several issues that limited its effectiveness and convenience. One of the main problems was the robot's poor battery life, which restricted its ability to complete larger cleaning tasks without frequent recharging. Additionally, the Looj often got stuck or even flipped over when encountering stubborn debris, like clumps of wet leaves or small objects. Design limitations also hampered its usability; users were required to remain on a ladder to control the robot, defeating the purpose of reducing the physical risks associated with gutter cleaning. The Looj was also unable to navigate gutter corners independently, necessitating manual repositioning by the user. Given these challenges, the Looj 330's practicality was often questioned, particularly in terms of whether it provided enough convenience to justify its cost, which was a few hundred dollars. Although it reduced the physical exertion involved in gutter cleaning, the need to frequently reposition the device and its susceptibility to battery and navigation issues detracted from its overall effectiveness (Hudy et al., 2021).

For those seeking alternatives to manual gutter cleaning but uninterested in the limitations of a gutter-cleaning robot, other options are available. Professional gutter cleaning services can offer a hassle-free solution, while tools like gutter-cleaning vacuums and power washers can simplify the task without the need for a robot. Gutter guards are another option, preventing debris from accumulating in the first place, though they, too, come with their own set of maintenance requirements (Hudy et al., 2021). The serious problem of clogged drains in urban areas, focusing on Chittagong, Bangladesh was addressed by Ahsan et al, (2019). Drainage issues, especially during the monsoon season, are a major headache in many cities. Heavy rains often overwhelm already damaged drainage systems, leading to waterlogging and flooding. The study focuses on the need for a practical, cost-effective solution to address these problems, which not only disrupt daily life but also pose health risks and contribute to urban flooding. The issue of drainage problems is particularly bad in certain areas of Chittagong, like Bahaddarhat, Sholoshahar, and Prabartak which are cities in Bangladesh. Traditional manual cleaning methods are found to be insufficient. These methods can't effectively manage the build-up of waste materials such as plastic bags, bottles, and other trash, which block the water flow and lead to frequent blockages and flooding. Moreover, accessing clogged drains is difficult and the manual work is labour-intensive, posing risks to workers. To tackle these issues, the authors propose a new robotic vehicle designed to clean drains more effectively. This robot has four wheels and uses a chain-sprocket mechanism to grab and remove waste. It can operate on its own, reducing the need for manual work and making the cleaning process more efficient. Ahsan et al. (2019), reviewed existing drain cleaning technologies and highlighted their limitations. For example, earlier robots, such as those used for sewer pipes or controlled by RF communication, struggled with the varied and tough conditions found in roadside drains. These robots either lacked the features needed for effective waste removal or required manual help at some stages, which reduced their overall effectiveness. The new robotic vehicle aims to overcome these issues by integrating several key features. The chain-sprocket mechanism drives the waste grabber, which has adjustable claws to handle different sizes and types of waste. The collected waste is put into a bucket on the robot and then moved to a disposal area via a conveyor belt. The system is designed to be simple and reliable, minimizing the risk of mechanical or electrical failures. The robot is controlled using Bluetooth and a custom app that allows for both manual and automatic operation. This flexibility means operators can step in when needed or let the robot work on its own. To test their design, the authors carried out field tests in various locations around Chittagong. These tests evaluated the robot's ability to handle different types of drains, waste levels, and challenging urban conditions. The results were encouraging, with the robot able to collect about 0.5 kg of waste per minute. The robot is also cost-effective, with a production cost of around 10,000 BDT, making it an affordable option for urban areas.

The paper by Rijmenam (2023) explored the rapidly advancing world of robotics, showing how robots have evolved from simple machines into complex systems that are changing industries and our daily lives. It begins by discussing recent developments in various types of robots, such as autonomous systems that reduce the need for human involvement in repetitive tasks and soft robots designed to interact safely with people. It also talks about swarm robotics, where multiple robots work together to achieve shared goals, increasing efficiency. In healthcare, medical robots are making significant progress, particularly in surgeries, where they assist doctors in performing precise operations. The integration of artificial intelligence with robotics is another major development, allowing robots to learn from their environments and improve over time. This is evident in the rise of exoskeletons and assistive devices that help people with mobility challenges regain their independence. The growing role of service robots, especially in elder care, where they provide companionship and reduce loneliness among older adults, should be noted as these robots are becoming more advanced, with features like speech recognition and natural language processing, making them better at fulfilling their roles. Additionally, it examines the development of humanoid robots, which can now perform tasks requiring human-like dexterity and agility. Examples such as Boston Dynamics' Atlas and Tesla's Optimus Bot show how these robots are starting to work in environments previously limited to humans (Metaverse Post 2023). On the business side, robotics is driving big changes in how companies operate. Robots are boosting efficiency and productivity and improving quality control and consistency in manufacturing. While there are concerns that robots might replace jobs, they are also creating new opportunities in fields like programming, maintenance, and robot design. This shift emphasizes the importance of reskilling and upskilling programs to prepare workers for these changes (Metaverse Post 2023). The increasing use of robots in different industries is expected to have a big impact on society, with both good and bad effects; one major concern is job loss. As robots and AI become more advanced, they can do many tasks that people used to do, especially repetitive or physical work.

A study by McKinsey Global Institute (2017) suggests that up to 800 million jobs worldwide could be lost to automation by 2030. While automation can help businesses by making them more efficient and reducing costs, it also puts many jobs at risk, which could lead to economic and social problems, especially in places that depend heavily on human labour. However, not all jobs are equally at risk. Jobs that require creativity, critical thinking, and human interaction are less likely to be automated, so people with these skills will still be needed. The rise of robots might also change how people interact with each other. As robots become more common in workplaces, human workers will need to adjust to new ways of working alongside machines. The increased presence of robots in daily life could also affect how people relate to one another. Also, using robots to care for elderly people, especially in countries like Japan where there are not enough caregivers, raises concerns about the quality of care and the potential loss of human interaction (McKinsey 2017). The rise of robots also impacts how wealth and power are shared. As machines take over more jobs, there is a risk that the benefits of automation will mostly go to those who own the machines. This concentration of wealth could get worse as automation leads to more job losses and income inequality. There is also a concern that a few companies that control the most advanced robots and AI systems could gain too much power, which could affect the economy and society. Despite these challenges, there are ways to reduce the negative effects of robots on society. Governments can invest in education and training programs to help workers gain the skills needed in a changing job market. Social protections, like income support and retraining programs, can also help workers who lose their jobs because of automation. Companies can help by creating new job opportunities that make use of human skills. For example, Amazon has invested a lot in robotics and automation but has also created thousands of new jobs in research, data analysis, and customer service (McKinsey 2017). They have also started programs like Amazon Future Engineer to help students from disadvantaged careers pursue careers in technology. Similarly, Siemens has developed the "Restart Project," which helps workers who have lost jobs due to automation find new employment through training, mentoring, and job placement support (World Economics Forum, 2020).

Robotics is transforming construction and building inspection by moving away from traditional, slow methods toward more precise, efficient, and safer robotic solutions. A noteworthy design involves a robot that learns to perform its tasks through an evolutionary algorithm. This robot was trained in simulation to identify waste, pick it up, and dispose of it using an iterative process that improves its performance over time (Jadhav et al., 2023). The robot uses infrared sensors to interact with its environment, and its behaviour is optimized through repeated simulations. In summary, the rise of robots and automation is likely to have a big impact on society, especially in terms of job loss, changes in social norms, and how wealth and power are distributed. However, by investing in education, providing social protection, and creating new job opportunities, we can work toward a future where robots and humans can coexist in a way that benefits everyone (Jadhav et al., 2023). The investigation into the design and development of a rover with a pick-and-place mechanism by Jadhav et al. (2023) introduces a possible solution to traverse rough terrains. The study emphasizes the importance of the rocker-bogie mechanism, which has been extensively adapted within robotics and space probe missions because of its improved stability and climbing capabilities over obstacles. The Mars Exploration Rover, which utilizes the rocker-bogie suspension system, has been pivotal in space missions (Jadhav et al., 2023). The investigation built models using CAD software, validating the design through simulations to achieve mechanical sustainability, structural integrity, and lightweight construction. The study further maintains the practicality of rocker-bogie suspension in stability, as the weight is distributed evenly over six wheels, with an ability to climb up to twice the wheel diameter obstacle while remaining in contact with the ground (Jadhav et al., 2023). The potential applications for rovers of this kind go beyond outer space to down-on-the-ground operations such as assisting astronauts with tasks on the ground and moving in post-disaster terrain conditions. There are advancements discussed in mobility control for rough and uneven surfaces, where analytical mode is a significant parameter in optimizing design and controlling (Jadhav et al., 2023). Robots are now crucial in building inspections. They come in several types: aerial robots (drones), ground robots (UGVs), hybrid robots, and custom-designed robots (Halder 2023). Drones are excellent for inspecting building exteriors and rooftops. They capture high-resolution images from different angles, which helps in maintenance and monitoring. However, drones face challenges like weather effects and image quality issues. Recent solutions include pairing drones with Lidar for better stability and using fuzzy logic systems to improve image accuracy. Ground robots, which can be wheeled or tracked, are ideal for indoor inspections and navigating complex terrain. They are commonly used for tracking construction progress and detailed interior inspections. Their ability to adapt to different surfaces makes them versatile for various tasks (Halder 2023). Hybrid robots blend features of both aerial and ground robots, offering greater flexibility. They might have wheels and propellers or other motion systems, allowing them to operate in tough environments that regular robots can't handle. For example, some have legs and magnetic pads for climbing steel structures, showcasing their adaptability (Afsari 2023).

Custom robots are designed for specific inspection needs that standard robots can’t meet such as robots that can climb walls or ropes, tailored for unique inspection challenges (Halder 2023). Robotic inspections are greatly improved by advanced sensors. Using multiple sensors together, such as RADAR, thermal cameras, accelerometers, and LiDAR, allows robots to detect and measure defects more accurately. For instance, combining thermal and regular cameras can find wet spots, while accelerometers and LiDAR help check if walls are vertical and floors are level (Afsari 2023). Future research should focus on improving different types of movement systems. Legged robots, like quadrupeds, are better for unstable or unfinished surfaces compared to wheeled UGVs.

However, they are expensive and not widely available, so cost-benefit studies are needed. Hybrid robots with various movement options, such as wheels and legs, offer versatile inspection capabilities. Research should continue to develop and test these hybrid robots in different scenarios. Using multiple robots with different strengths can improve inspection efficiency. For example, combining UGVs and UAVs provides both aerial and ground views. However, integrating different robots poses challenges with software compatibility and data formats. Future work should focus on creating universal protocols and data formats to enable smooth collaboration between different robots (Halder 2023). While robots can make inspections safer by performing risky tasks, they also introduce new risks. There's a need for safety regulations covering all types of robots, not just drones. Future research should address these safety issues and develop guidelines to manage risks, insurance, and liability concerns ref. Good data transmission is vital, especially in places without Wi-Fi. Developing direct communication protocols between devices can enhance robot performance. Using Internet of Things (IoT) technology to connect robots with other smart devices on-site can make inspections more robust and efficient. Effective human-robot collaboration is key to maximizing robotic performance. Shared autonomy, where humans handle higher-level decisions and robots manage routine tasks, can increase efficiency. Training programs, including VR simulations, can help workers use robots effectively. Future research should explore these training needs and integrate robotics into construction education to prepare workers for new technologies (Afsari 2023). The drainage cleaner is a special machine used to remove garbage and sewage automatically. The aim of mechanical drainage cleaner is to replace the manual work required for drainage cleaning systems. Hence, the automatic sewage cleaning system is implemented. This is majorly concentrated in the clearance of gaseous substances that are treated separately so the flow of water efficiently (Kumaresan 2016). Blockage is the major cause of flooding in metro cities, hence GSM technology is used in those areas by designing the blockage detection system (Kumaresan 2016).

Sewage inspection robots serve to evaluate the conditions of a pipeline, detect faults, and make minor repairs in environments where human access is limited in hazardous conditions (Knedlová et al., 2017). There are usually two classes into which robots fall: fully autonomous and cable-tethered systems. Autonomous robots can inspect expansive networks of pipelines, but battery life and retrieval challenges in instances where failure has occurred hamper their proper functioning (Bílek et al., 2017). Cable-tethered machines, on the other hand, are more suited to retrieving the robot, although power-line links might limit them in terms of distance range. Various mechanical designs exist for pipeline inspection, including wheeled, caterpillar, and snake-like robots. Each design is best suited to a specific combination of pipeline geometry and surface conditions (Sámek & Chalupa, 2017). Modern inspection robots are built as robust, waterproof, and modular devices that increase flexibility and durability to the solicitudes of the harsh sewage environment (Knedlová et al., 2017). The work of Kumar et al. (2017) focuses on the pressing need for sustainable waste management solutions that transcend outdated disposal methods, emphasizing the importance of waste segregation, resource recovery, and the development of engineered landfill sites and waste-to-energy facilities (Smith et al., 2017). The paper highlights the significant role of the informal sector in recycling and the challenges posed by inadequate waste collection and processing infrastructure, ultimately advocating for a comprehensive overhaul of current systems in order to protect public health and the environment while fostering economic opportunities (Velis et al., 2017). Through an analysis of an international seminar organized by the Council of Scientific and Industrial Research-National Environmental Engineering Research Institute, the article provides insights into collaborative efforts needed across South Asian nations to enhance waste management practices and policies (Fowler et al., 2017).

The issue of manual scavenging, however, continues to raise its ugly head in the Indian scenario, compounded by numerous constitutional, legislative, and administrative interventions for its liberation (Maurya, 2018). The practice is more of a caste-based discrimination, with manual scavenging being relegated to certain groups, predominantly members of Dalit from marginalised communities, since they have been subjected to oppression for ages without any substitute means of earning (Maurya, 2018). The Swachh Bharat Abhiyan has tried to work towards eradicating open defecation through improvements in sanitation infrastructure, but little has changed in terms of ending manual scavenging since many municipalities still employ manual cleaners for sewage and solid waste disposal (Maurya, 2018). Problems of legislation ineffectiveness, the weak enforcement of laws like the Prohibition of Employment as Manual Scavengers and Their Rehabilitation Act of 2013, and rampant corruption have all combined to sustain these practices persisting in states like Gujarat, Madhya Pradesh, Uttar Pradesh, and Rajasthan (Maurya, 2018). Cultural acceptance of manual scavenging in the concerned communities, coupled with socio-economic limitations, serves to further impaired any proposal for genuine reforms. Untested policy-makers along with rehabilitation processes are going on without a deeper commitment into abolishing manual scavenging and securing good health for the communities involved on grounds of social stigmatization and this will often mean the customary passage of manual scavengers from one generation to another (Maurya, 2018). Automation is an essential component of current industrial use, but adequate sewage disposal is a recurring issue that usually leads to unsafe working conditions for manual scavengers (Ghatage et al., 2024). Conventional cleaning of drains puts workers in contact with dangerous microbes, which exposes them to the risk of malaria and typhoid (Gaikwad et al., 2024). To mitigate these risks, different automated solutions have been suggested by researchers, such as electronic bucket systems (Sathiyakala, 2024), mechanical drain cleaners (Ganesh, 2024), and autonomous sewage cleaning machines (Kumaresan, 2024). The usage of these systems increases waste removal efficiency and decreases the load on human labour (Patil et al., 2024). In addition, advances in technology, including sensor integration and remote-control features, enhance the reliability of automation, making them a feasible solution for mass deployment (Shinde, 2024). In light of growing pressure for green drainage management, innovation in semi-automatic gutter cleaners is a giant leap towards improved waste disposal systems that are safer and more efficient (Shinde, 2024).

This study seeks to fill this gap by creating an Arduino-based robotic waste disposal system to automate the process of cleaning open gutters in an efficient manner. With sensors and a robotic arm, the system improves waste collection while reducing human intervention in hazardous conditions. Feasibility tests will evaluate its practicality in actual environments to ensure efficiency and reliability. The research adds value to public health and environmental sustainability through the provision of an inexpensive and scalable approach to waste disposal. Automation alleviates the need for human effort, enhancing safety and efficiency with the possibility of large-scale implementation ref. Through the resolution of a severe urban sanitation challenge, this study opens the way for intelligent and sustainable waste disposal practices. The rest of this paper is structured in such a way that the design methodology is described in section 2, the results and discussion are elaborated in section 3 and section 4 houses the conclusion of this research.

2. Methodology

The advancement of robotics has resulted in novel solutions for risky operations like drainage cleaning, where manual scavenging is very dangerous to one's health. Conventional techniques, such as manual scavenging and pump systems, are not effective in solving the problem of solid waste buildup, causing clogging of drains and environmental risks (Sharmili, 2017). To address these drawbacks, scholars have introduced automated drainage cleaning robots with robotic arms, GSM communication, and Arduino-based controllers, which facilitate real-time observation and waste disposal efficiency (Saarika, 2017). Likewise, the development of sewer inspection robots has proven promising with autonomous maintenance and monitoring capabilities, minimizing human intervention and maximizing safety for workers (Kumar, 2020). The combination of water level sensors and RF communication further enhances these systems with timely notifications of drainage conditions to avoid overflow and enhance urban sanitation (Patel, 2019). This technology shows the increasing use of automation in addressing key sanitation challenges while reducing human exposure to harmful environments. Clogs in underground sewers are one of the most significant challenges created by the disposal of solid wastes improperly, creating health and environmental hazards. Research has shown that plastics, rags, sanitary items, and white cement waste are the typical materials that build up in sewer pipes, producing severe clogs that need manual clearing or costly high-pressure water jet systems (Sulthana et al., 2023). The dangerous aspect of sewer cleaning, mainly from poisonous gases like hydrogen sulfide (H_2S) and methane, has claimed many lives of manual scavengers in India (Kumar et al., 2023). Earlier experiments in automating sewer cleaning involve equipment like the Bandicoot robot, which is intended for cleaning manholes, but its failure to remove pipe blockages is still a major drawback (Mathur et al., 2023). Furthermore, experimental robots that employ thrusters and ultrasonic sensors have shown promise in the detection and identification of obstructions but are frequently not equipped with the mechanisms required for successful waste removal (Mohile et al., 2023). More effective is the design of an autonomous robot integrated with an inertial navigation system and a mechanical waste-clearing mechanism, lessening reliance on human use while limiting expenses (Vibha et al., 2023).

As discussed in the above section, the gutter cleaning situation in India is being tackled by big machines. But nothing is being done in small side gutters on the road. Hence in this study, we will show the steps taken to design such a robot for gutter cleaning which will help society. The drains (see figure 2) are found in smaller roads which are not big enough to install the full drainage system with drains and large sewage pipes.

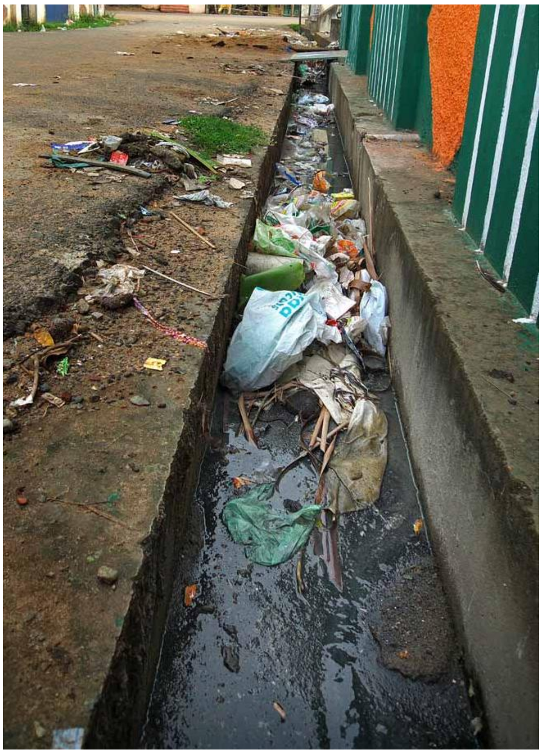


Figure 2: Example of a Drain in India

2.1 The Design of the Robot

The first 2D design was made on Microsoft Whiteboard, where measurements were taken with precision (Figure 3). It was then converted into a 3D model with the help of CAD software Onshape. The most important design features are a garbage collection unit and a robotic gripper arm for waste gathering, as illustrated in Figure 4. The design was selected because it is efficient—it has enough room inside the walls of the "box" to accommodate the required electronics while optimizing the storage capacity for gathered waste. Because the power source and transmitter are outside, there is more space for storing waste. There is a drainage system at the base to prevent any moisture accumulated inside from building up and allowing mould to form.

There are ultrasonic sensors on the sides and the back for minimum obstacle detection and a front-mounted camera to allow the operator a good view of what is ahead of the robot. Arduino Uno acts as the controller, designed with Arduino C++ to coordinate robotic arm motion and system functionality overall. Servo motors are used to drive the arm and are held firmly with thick wire metal to guarantee rigidity.

Sensor logic is deployed to translate data from ultrasonic sensors in a way that makes the system react to obstructions and vary motion accordingly. The robot is also controlled manually with a wired remote, which is free from interference due to the stable connection. Besides, an outside power source is utilized, provided through insulated wire, that extends the operational periods without frequent need for recharging. We could opt to stick with this model since it reconciles efficiency, storage, and stability. However additional improvements in sensor integration and autonomous functions might make it perform better in actual drainage cleaning applications.

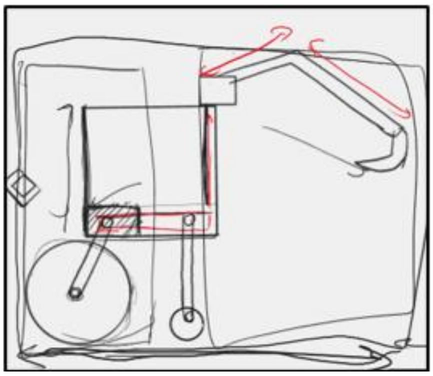
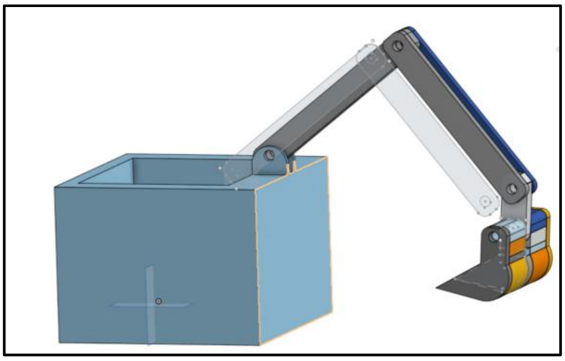


Figure 3: The 2D design (I have changed the model of the base from the above to a 4-wheel system with the same large size wheels for stability and grip and to raise the rover height)



This will be attached to a base as shown below

Figure 4: The 3D design

2.2 The Cost of the Robot

The minimum cost of creating one unit of the Automatic Drainage Cleaning System (ADCS) is estimated to be $177(1$ = 86.7₹). The most expensive component is the chassis at about $96 (54.4%), followed by Arduino and electronics (ROBU.IN, 2025). 3D printing materials ($18) and servo motors ($17) also have a high contribution to the overall cost. The cost can also be reduced through bulk procurement of the materials. Increased production can lower the overall cost per unit by a substantial amount. Buying Arduino boards, servo motors, and electronic parts in bulk can bring wholesale discounts and lower unit costs. The cost of 3D printing may also come down with increased material efficiency and designs optimized for minimal usage. Collaborating with municipal authorities or waste organizations could lower costs further through subsidies or bulk manufacturing bonuses.

Aside from startup production expenses, operational costs also involve electricity usage, maintenance, and replacement of parts.

- Power Consumption: Projected at 100+ mAh per unit, which is equivalent to very little energy consumption, Additionally, an external battery will be used and charging will not require a very small addition to municipal electricity bills.
- Maintenance and Repair: Regular servicing will be needed, especially for motor lubrication and clearing out debris.
- Labour Costs: Minimal, with reduced manual handling. Periodic inspection by a technician might be required, on average $20–$50 per month per unit.

With optimal component sourcing and the utilization of automation, the ADCS is an inexpensive and scalable option for waste treatment in urban drainage systems.

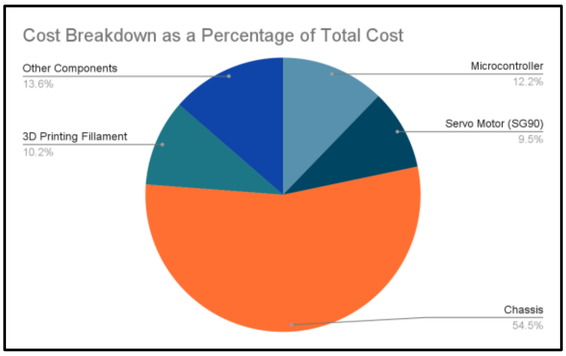


Figure 6: Breakdown of Cost of Building Robot

2.3 The Implementation of the Automatic Drainage Cleaning System

The successful deployment of the Automatic Drainage Cleaning System (ADCS) involves a multi-phase process, starting from prototype development to large-scale implementation. Initially, the system will be constructed using Arduino Uno, 4 MG90 servo motors, a metal chassis (aluminium or steel) and 3D-printed components for the bin, the robotic arm as shown in figure 7. This will be followed by testing to assess its efficiency in waste detection and removal. This phase will focus on fine-tuning the design, the robotic arm functionality, and the chassis durability to meet the demands of real-world drainage environments.

Figure 7: Prototype of robotic arm made by 3D printing for collecting waste. Controlled by Arduino Uno, 4 MG90 servo motors and 2 joystick modules

After refining the prototype, pilot deployments will take place at selected drainage sites with varying waste compositions. Through some testing, it was seen that the arm on its own is capable of doing the task, however more data needs to be collected on the whole robot. Data gathered will include efficiency in movement, strength of the robot and the waterproof capability which will prevent damage to circuits. To facilitate widespread adoption, ADCS units will be integrated into existing municipal sanitation infrastructure through collaborations with local authorities and waste management organizations. A key strategy to reduce costs will involve bulk procurement of components, lowering manufacturing expenses. Additionally, a digital monitoring system could be incorporated along other things such as AI, enabling real-time tracking of waste collection efficiency, predictive maintenance and also autonomous waste collection, further optimizing operational performance.

Sustained functionality will require periodic servicing, such as motor lubrication, sensor recalibration, and debris removal. A municipal dashboard or mobile app could be developed for remote management and control, allowing authorities to monitor and optimize the system. In the long term, AI-driven waste classification algorithms will be integrated to improve sorting efficiency, allowing the system to adapt to different waste types and enhance resource recovery.

Future advancements will focus on scaling ADCS to suit various urban environments, enhancing automation capabilities, and expanding its scope to include broader waste management applications. Research into more durable, eco-friendly materials will ensure the system's longevity, while machine learning algorithms will improve autonomous waste categorization and removal (Satav et al., 2023). Through this strategic approach, ADCS can establish itself as a cost-effective, automated solution that not only improves sanitation but also reduces the health risks faced by manual waste collectors. Ultimately, this innovation marks a crucial step toward sustainable urban waste management and environmental protection.

2.4 The Feasibility and Limitations of the Robot

The Automatic Drainage Cleaning System (ADCS) is capable of operating well under real-life conditions, being a solution to the shortcomings of conventional manual waste collection processes. In contrast to manual cleaning that subjects workers to unsafe conditions, the ADCS has less human contact, thus lowering medical risks. The approximate cost of producing one ADCS unit is $193 (₹16,100). For manual cleaning, however, there is a workforce of labourers who are paid around $5–$10 (₹415–₹830) per day. Municipalities use several workers to clean daily, which translates to a monthly labour expenditure of $150–$300 (₹12,500–₹25,000) per worker. In the long run, the ADCS is a more economical option, particularly when made in bulk quantities, lowering costs per unit and long-term municipal expenditures. The ADCS can be deployed on a large scale but comes with some constraints. One such constraint is power consumption since the system needs more than 100mAh, implying that a trustworthy power source for constant operation would be required. Another concern is durability as a result of water exposure, trash, and diverse environmental conditions, which calls for strong materials and waterproofing features.

Maintenance also comes into play since parts like motors and sensors will require maintenance from time to time to run at optimal capacity. The maintenance will mainly include cleaning debris from the rover. Software constraints also contribute to scalability. Although the ADCS is remotely operated, the incorporation of artificial intelligence for autonomous waste detection and collection will enhance its efficiency. This, however, calls for improvement in machine learning algorithms and sensor technology. Regardless of the above limitations, with ongoing optimization and mass production, the ADCS can be scaled up for use, thereby making drainage cleaning safer, more efficient, and economical.

3. Results and Discussion

The rover which is in the process of development is a remote-controlled vehicle designed to clean roadside open sewers in India to address the pressing issue of poor sanitation. Using Arduino to manage its movements, the rover will feature a robotic arm to efficiently collect waste from the sewers. This arm was extensively tested to check the load capacity, manoeuvrability and efficiency of picking waste. It was successfully able to pick up large amounts of dry waste such as plastic and sand, it was also able to dig and lift up marshy semi-solid substances as well such as wet mud when the base was securely fastened. Lastly, the bucket is also able to carry liquids such as water without dropping when carefully handled.

The design's aim was to focus on durability and reliability to ensure it can withstand the challenges posed by this environment. In the future we can improve upon the design using Alfeo et al. (2019) paper which proposes a new autonomous waste management paradigm through swarm robotics. The paper examines the capability of bio-inspired foraging techniques, including multiple-place foraging (MPF) and stigmergy-based navigation, to maximize urban waste collection. Contrary to the conventional centralized waste management model, this framework uses a swarm of autonomous robots with RFID sensors, LiDAR, and computer vision to detect, pick up, and carry waste optimally. Through the emulation of real urban settings based on GIS data, the research shows that the swarm-based system achieves a significant drop in uncollected garbage and overflowing bins as opposed to the traditional truck-based collection. The authors also mention the benefits of decentralized coordination that enable the robots to respond dynamically to patterns in waste distribution, thus maximizing efficiency. The findings reveal that MPF-based swarm robotics performs better compared to traditional approaches in urban settings, albeit with issues in optimizing swarm behavior and real-world deployment (Alfeo et al., 2019).

This project holds great social relevance as it provides a safer and more efficient solution for cleaning open sewers. In many areas of India, manual labour is still used to clear drains, putting workers at risk of exposure to diseases. The rover aims to reduce this risk by minimizing human contact with hazardous waste. By improving sanitation, it can help curb the spread of waterborne diseases and contribute to a healthier, more hygienic living environment. The next step in the project involves testing whether the robotic arm or the conveyor belt will be more effective for waste collection. Once this decision is made the building of the rover will be completed and ready for field testing for assessment of its performance under real-world conditions. These tests are crucial to refining the design and ensuring its practical application. The innovation in this design lies in the use of remote-control technology to tackle sewer waste management, eliminating the need for hazardous, hands-on collection. This practical, cost-effective solution has the potential to make a meaningful impact on healthcare and sanitation in India. Artificial intelligence will be implemented into the rover's system, enabling it to operate autonomously, further enhancing its usefulness. In summary, autonomous waste collection has come a long way with designs specifically made for different environments, ranging from beaches to interior areas. Despite this, the cost of production is still very high. Researchers are therefore striving to come up with cost-friendly but effective robots to improve waste management. Such systems can lead to cleaner environments and better public health, particularly in times of health emergencies such as the COVID-19 pandemic. Their applications vary from urban sanitation to industrial waste management, mitigating human contact with toxic waste. Future enhancements may revolve around integrating improved AI to enable smarter routes, improved sensors for accurate identification of waste, and a strengthened chassis for its longevity. Second, working alongside local governments and organizations can support scaling up, enabling these robots to be applied in all 28 states throughout the nation.

References

[1] Shreya Gupta et al 2021 J. Phys.: Conf. Ser. 1950 012023

[2] Narasimhulu, G., L.V.R.G. Prasad, Ponugoti Vinay, Boggula Kalyan, Rathod Mahesh, and Adike Shiva Sai. 2023. *Design and Fabrication of Robotic Clog Remover Vehicle. International Research Journal of Modernization in Engineering, Technology and Science* 5 (4). https://www.doi.org/10.56726/IRJMETS37084.

[3] Khandare, S., Badak, S., Sawant, Y. and Solkar, S., 2018. Object detection based garbage collection robot (E-Swachh). International Research Journal of Engineering and Technology (IRJET), 5(03).

[4] Khan, Fahim & Islam, Md Shahriar & Hossain, Md. (2016). Design Aspects of an Excavator Arm. International Review of Mechanical Engineering (IREME). 10. 437. 10.15866/ireme.v10i6.9395.

[5] Ali, Hussein & Hashim, Yasir & Alsakkal, Ghadah. (2022). Design and implementation of Arduino based robotic arm. International Journal of Electrical and Computer Engineering (IJECE). 12. 1411. 10.11591/ijece.v12i2.pp1411-1418.

[6] Khan MA, Khan DMZ, Khan H, Hanzla M, Jamal M, Khalid T, Ullah N (2020) Garbage collector robot. Indian Journal of Science and Technology 13(20): 2065-207

[7] Muthugala, M. A. Viraj J., Povendhan Palanisamy, S. M. Bhagya P. Samarakoon, Saurav Ghante, Anantha Padmanabha, Mohan Rajesh Elara, and Dylan Ng Terntzer. 2021. "Raptor: A Design of a Drain Inspection Robot" *Sensors* 21, no. 17: 5742. https://doi.org/10.3390/s21175742

[8] Sharma A; Singh A; Singh M (2019). Automatic Drainage Cleaning System.

[9] W. Hudy, U. Marikutsa, K. Pytel, S. Gumula, H. Noga and M. Niedbalec, "Design and Construction of a Gutter-Cleaning Robot as an Example of Engineering Education," 2021 IEEE XVIIth International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH), Polyana (Zakarpattya), Ukraine, 2021, pp. 38-41, doi: 10.1109/MEMSTECH53091.2021.9468040.

[10] Ahsan, Md, Munna, Mohammed Saifuddin, Nayeem, Abu (2019/12/26) 268 271 "Design and Implementation of a Drain Cleaner Robotic Vehicle" 10.1109/ICECTE48615.2019.9303536

[11] Halder S, Afsari K. Robots in Inspection and Monitoring of Buildings and Infrastructure: A Systematic Review. *Applied Sciences*. 2023; 13(4):2304. https://doi.org/10.3390/app13042304

[12] Mckinsey Global Institute (2017, December 6). Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation.

[13] World Bank. 20 October 2020. The Future of Work in Developing Economies. World Bank Group. Accessed 5 September 2024. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/844891582835065244/the-future-of-work-in-developing-economies

[14] Dhairyashil Jadhav et al 2023 J. Phys.: Conf. Ser. 2601 012007

[15] Dr K. Kumaresan et.al. "Automated Sewage Cleaning Equipment", International Conference on Explorations and Innovations in Engineering and Technology ,2016

[16] Knedlová, Jana & Bílek, Ondřej & Sámek, David & Chalupa, Petr. (2017). Design and construction of an inspection robot for the sewage pipes. MATEC Web of Conferences. 121. 01006. 10.1051/matecconf/201712101006.

[17] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.

[18] World Bank. 5 October 2024. *Poverty and Inequality Platform (PIP): India Country Profile.* World Bank Group. Accessed 5 September 2024. https://pip.worldbank.org/country-profiles/IND

[19] Kumar, Sunil, Stephen R. Smith, Geoff Fowler, Costas A. Velis, S. Jyoti Kumar, Shashi Arya, Rena Rena et al., 2017. "Challenges and opportunities associated with waste management in India", Royal Society Open Science (3), 4:160764. https://doi.org/10.1098/rsos.160764

[20] Maurya, Harsh. "A Contemporary Outlook to Manual Scavenging in India: Swachh Bharat Abhiyan, Gandhian Perspective & Other Dimensions." *International Journal of Creative Research Thoughts (IJCRT)* 6, no. 2 (April 2018): 353–360. ISSN: 2320-2882. www.ijcrt.org.

[21] Ministry of Jal Shakti, Department of Drinking Water and Sanitation. 2014. *Swachh Bharat Mission.* Government of India. Accessed 3 September 2024. https://swachhbharatmission.ddws.gov.in/about_sbm

[22] Athar,Sohaib; White,Roland; Goyal,Harsh. *Financing India's urban infrastructure needs: Constraints to commercial financing and prospects for policy action (English).* Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099615110042225105/P17130200d91fc0da0ac610a1e3e1a664d4

[23] Sharmili, S.A., Saarika, T., & Malar, R.S. (2017). Intelligence Drainage Cleaning Using Arm robot.

[24] S Fouziya Sulthana et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 912 022049

[25] Bhagirathi, V., Sutar Abhishek Umesh., Naik Rohan Pradip., Wagh Kaustubh Rama., & Pranil Man Joshi. (2020). Automated Garbage Collection Rover. Journal of Emerging Technology and Innovative Research, 7(6), 652-660.

[26] AI Based Prediction Algorithms for Enhancing the Waste Management System: A Comparative Analysis. Vanya Arun, E. Krishna Rao Patro, V.S. Anusuya Devi, Amandeep Nagpal, Pradeep Kumar Chandra, Ali Albawi

[27] Satav, Anushka & Kubade, Sunidhi & Amrutkar, Chinmay & Arya, Gaurav & Pawar, Ashish. (2023). A state-of-the-art review on robotics in waste sorting: scope and challenges. International Journal on Interactive Design and Manufacturing (IJIDeM). 17. 1-18. 10.1007/s12008-023-01320-w.

[28] Antonio Luca, Alfeo & Castello, Eduardo & Lizarribar, Yago & Grignard, Arnaud & Alonso Pastor, Luis Alberto & Sleeper, Dylan & Cimino, Mario Giovanni C.A. & Lepri, Bruno & Vaglini, Gigliola & Larson, Kent & Dorigo, Marco & Pentland, Alex. (2019). Urban Swarms: A new approach for autonomous waste management. 10.1109/ICRA.2019.8794020.