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THE TREND OF APPLICATION OF SERVICE ROBOTS FOR INSPECTION, PLANNED MAINTENANCE AND REMOVAL OF DISRUPTIONSIN PIPING SYSTEMS

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Наразі світ знаходиться на початку четвертої промислової революції – Індустрії 4.0, кінцевою метою якої є зробити все розумним: як виробничі процеси в галузі, так і обслуговування системи. У навколишньому середовищі є багато систем трубопроводів, таких як: водо-газо-нафтогони, каналізація тощо, які потребують постійного обслуговування. Інакше кажучи, вони вимагають періодичних перевірок для виявлення таких неполадок, як корозія, тріщини, деформації або інші перешкоди. Сервісні роботи для огляду та обслуговування дуже зручні для перевірки систем трубопроводів. Крім того, вони цікавлять багатьох дослідників у цій галузі, тому існує незліченна кількість розроблених сервісних роботів, які зараз використовуються. Сервісні роботи для перевірки системи трубопроводів використовуються для перевірки та надають візуальну інформацію зсередини відповідної труби. Коли сервісний робот рухається трубою, на камеру фіксується його переміщення, що забезпечує отримання відео про внутрішній стан труби. Відео можна використовувати пізніше, щоб після виявлення неполадок системи трубопроводів прийняти правильне рішення щодо його подальшої робити. У статті представлено тенденцію застосування сервісних роботів для перевірки стану труб. Показано ряд конструкцій цих сервісних роботів, які вже впроваджуються. Сервісні роботи ефективно знижують наслідки і кількість усіх проблем, що пов'язані з обслуговуванням, очищенням та перевіркою систем трубопроводів. Зростаюча тенденція застосування сервісних роботів пов'язана з впровадженням базових технологій Індустрії 4.0, оскільки її метою є постійне отримання інформації про роботу системи. Для огляду небезпечних для здоров'я працівників трубопровідних систем і установок розроблено різноманітні роботизовані системи. Сервісні роботи керуються камерою, датчиком або простими інструментами. Більшість сервісних роботів призначені для резервуарів, систем трубопроводів для всіх матеріалів, для огляду вентиляційних отворів і труб повітряних систем, каналізації, атомних станцій або роботи в агресивних середовищах. Очікується, що найближчим часом розвиток і застосування сервісних роботів для інспекції продовжиться. Сервісні роботи ефективно зменшують усі проблеми, пов'язані з обслуговуванням, очищенням та перевіркою систем трубопроводів.

Ключові слова: сервісний робот, перевірка, трубопровід, неполадки,обслуговування.

В настоящее время мир находится в начале четвертой промышленной революции – Индустрии 4.0, конечной целью которой является сделать все разумным: как производственные процессы в отрасли, так и обслуживание системы. В окружающей среде имеется много систем трубопроводов, таких как: водо-газо-нефтепроводы, канализация и т.д., требующие постоянного обслуживания. Другими словами, они требуют периодических проверок для обнаружения таких неполадок, как коррозия, трещины, деформации или другие помехи. Сервисные работы по осмотру и обслуживанию очень удобны для проверки систем трубопроводов. Кроме того, они интересуют многих исследователей в этой области, поэтому существует множество разработанных сервисных роботов, которые сейчас используются. Сервисные роботы используются для проверки системы трубопроводов и предоставляют визуальную информацию изнутри соответствующей

трубы. Когда сервисный робот двигается по трубе, на камеру фиксируется его перемещение, что обеспечивает возможность видеосъемки о внутреннем состоянии трубы. Видео можно использовать позже для обнаружения неполадок системы трубопроводов и принятия правильного решения о дальнейшей его работе. В статье представлена тенденция применения сервисных роботов для проверки состояния труб. Показан ряд уже внедряемых конструкций этих сервисных роботов, которые эффективно снижают действие и количество проблем, связанных с обслуживанием, очисткой и проверкой систем трубопроводов. Растущая тенденция применения сервисных роботов связана с внедрением базовых технологий Индустрии 4.0, целью которой является получение текущей информации о работе системы. Для осмотра опасных для здоровья работников трубопроводных систем и установок разработаны разнообразные роботизированные системы. Сервисные работы управляются камерой, датчиком или простыми инструментами. Большинство сервисных роботов предназначено для резервуаров, систем трубопроводов для всех материалов, для осмотра вентиляционных отверстий и труб воздушных систем, канализации, атомных станций или работы в агрессивных средах. Ожидается, что в ближайшее время развитие и применение сервисных роботов для инспекции продолжится. Сервисные работы эффективно снижают все проблемы, связанные с обслуживанием, очисткой и проверкой систем трубопроводов.

Ключевые слова: сервисный робот, инспектирование, трубопровод, неполадки, обслуживание.

The world is currently at the beginning of the fourth industrial revolution – Industry 4.0, whose ultimate goal is to make everything intelligent, both production processes in the industry and system maintenance. The environment around us has plenty of piping systems such as: water, gas, oil, sewage, etc., which need to be continuously maintained. In other words, they require periodic inspections to identify errors such as corrosion, cracks, deformations, or obstruction with obstacles. Service robots for inspection and maintenance are very convenient for the inspection of piping systems. In addition, they are a point of interest to many researchers in the field, so there are countless developed service robots that are currently in use. Service robots for inspection of piping system are used for inspection and provide visual information from inside the corresponding pipe. When the service robot moves through the pipe, it records the inside with a camera and provides us with visual information, i.e., provides a video of the inside of the pipe where we can locate the error. We can use the video later to establish the condition of the recorded piping system and make the right decision what to do. The paper presents the trend of application of service robots for inspection. A number of constructions of these service robots that are already in implementation are shown. Service robots effectively reduce all problems related to the maintenance, cleaning and inspection of piping systems. The growing trend of service robots application is due to the implementation of basic technologies of Industry 4.0 because its aim is to receive the information about the operation of a system all along. Various robotic systems have been developed for inspection and examination of piping systems and plants that are dangerous to workers' health. Service robots are controlled by camera, sensor or simple tools. Most service robots for inspection are intended for tanks, piping systems for all materials for inspection of ventilation openings and pipes of air systems, sewer systems, nuclear plants, or work in aggressive environments. It is expected that the development and application of service robots for inspection will continue to grow in the nearest future. Service robots effectively reduce all problems related to the maintenance, cleaning and inspection of piping systems.

Keywords: service robot, inspection, pipeline, error, maintenance.

INTRODUCTION

The development of the core technologies of Industry 4.0, including robotic technology, is responsible for the development of a large number of service robot constructions for professional use [1]. Their implementation is necessary where human presence is impossible, such as work in systems that are dangerous to human health, e.g., nuclear plants, high temperatures, metal casting, production of glass and ceramic products, processes involving high pressure painting, welding, grinding, polishing, etc. Also, their implementation is necessary in places which man is not physically able to access such as piping systems, both below and above ground. Service robots that belong to the group for professional use have a wide range of implementations in the environment. With the implementation of Industry 4.0 core technologies their application is continuously increasing. The implementation of service robots for professional services is shown in Figure 1 [2].

As shown in Figure 1, their implementation can be found in: logistics, inspection, environment, medicine, agriculture, professional cleaning, defense, construction, exoskeletons, rehabilitation, etc. They are especially welcomed in dangerous conditions or places inaccessible to humans (e.g., nuclear plants, high temperatures, inaccessible plants such as pipelines, etc.). Since global manufacturing industry is implementing Industry 4.0, innovations in robotics, automation, and artificial intelligence (AI) are gaining ground in all manufacturing processes where humans and robots work together. The companies must be ready to implement them to meet consumer demand in the global marketplace [3-4].

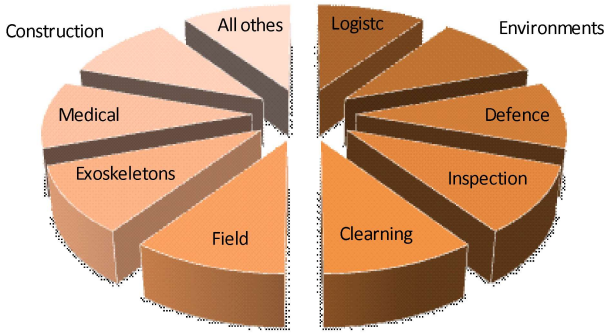

Figure 1 – The implementation of service robots for professional use

Service robots for inspection of piping systems are very good for inspection and maintenance of piping systems. The process of maintaining the piping system includes three main activities:

- *Inspection,* which includes activities that monitor and provide information on the state of the water supply system in order to enable the prediction of disturbances or early detection of disruptions.
- *Scheduled maintenance,* which includes activities in which elements of the system are replaced or repaired according to a predetermined schedule, in order to avoid or reduce the frequency of disruption.
- *Disruption management*, which includes activities that change the elements of the system and restore the desired state after the disruption.

Maintenance of piping systems requires access to dynamic environments. The tasks in maintaining these systems may be less predictable, both in terms of the nature of the tasks and the frequency of maintenance or any delays between the tasks. Service robots for inspection are used occasionally, unlike robots that are active all the time and are cost-effective, but can pay off with one application, for example in a nuclear plant or gas pipeline system where gas is lost and we are unable to establish the reason and how to fix it [5,6].

RESEARCH METHODOLOGY

In order to analyze the trend of service robots for professional use as well as the application of service robots for inspection and scheduled maintenance, we have taken statistics from the International Robotics Federation (IFR), the United Nations Economic Commission for Europe (UNECE) and the Organization for Economic Co-operation and Development (OECD), which have aggregate data coming from about 750 robot companies [9-20]. Statistical analysis methods and the MS-Excel software system were used to calculate the parameters of statistical descriptions and graphical presentation of data.

RESULTS

Development and implementation of new technologies, such as: robotic technologies, new generation of digital technologies, artificial intelligence, machine learning, internet, genetic modification, new types and methods of energy and information storage, quantum computing, 3-D printing, genetic engineering and biotechnology in the manufacturing processes of the industry, makes automation flexible which leads to reduced product life and increased productivity. In addition, the implementation of innovations in robotic technology enables the development of a new generation of robots that are aware, connected, and intelligent, while control technology enables their autonomous adaptation based on internal or external command. In other words, they are equipped with a powerful computer that allows autonomous decision making and algorithm-based self-learning process. Next-generation robots communicate with the environment, understand the environment through models, automatically generate a program based on planned tasks, understand human actions, and follow human social norms. The development of robotic technology is credited with the increasing trend of implementation of service robots for professional use, as shown in Figure 2.

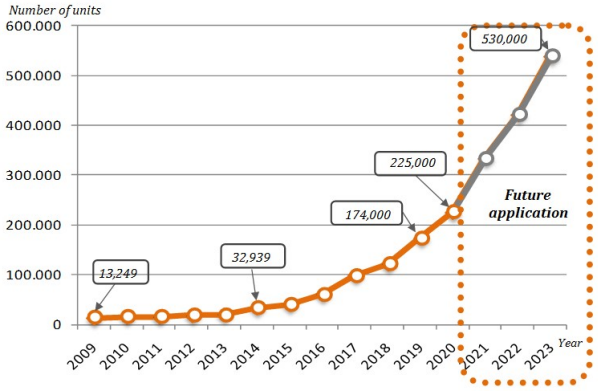

Figure 2 – The trend of implementation of service robots for professional use in the world in the period 2009-2020 with predictions of application until 2023[11-20]

Based on Figure 2, we come to the conclusion that the implementation of service robots for professional use has been progressing exponentially in the last ten years. In 2009, 13.249 service robot units were applied, while in 2020, the application amounted to 225.000 units of service robots. In other words, it is an increase of about 17 times, which is the results of the implementation of Industry 4.0 and its base technologies. It is estimated that this trend will continue until 2023, when the application of about 530.000 service robot units for

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professional use is predicted. Service robots for inspection are precisely those used for inspection and scheduled maintenance of piping systems, which will be analyzed in this paper. We will show the trend of application of service robots for inspection, as illustrated in Figure 3.

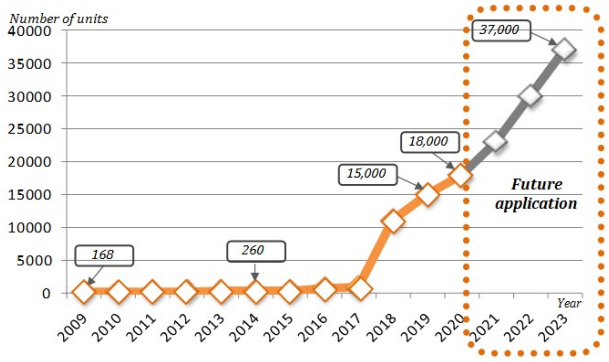

Figure 3 – The trend of implementation of service robots for inspection in the world in the period 2009-2020 with predictions of application until 2023[11-20]

The trend of implementation of service robots for inspection in the world is shown in Figure 3. As can be seen, the implementation of robots has slightly increased, from 168 robot units in 2009 to 800 robot units in 2017. There has been a high implementation in the last three years, so that in 2020, about 18.000 robot units were implemented. The increasing trend of implementation in the recent years has been provided thanks to innovations from advanced technologies and companies that implement innovative technologies of Industry 4.0. It is estimated that this increased trend will continue, so that the implementation of about 37.000 service robot units for inspection is predicted by 2023. The implementation of service robots for inspection and maintenance is inevitable in all systems that man cannot access, such as water supply systems, or systems in which human health is endangered, such as nuclear plants, high temperature systems, etc. [7-9].

IMPLEMENTATION OF SERVICE ROBOTS FOR INSPECTION AND MAINTENANCE OF PIPING SYSTEMS

Piping systems for water, gas, oil, sewage, and tanks need to be inspected periodically to notice the accuracy or errors that occur, in order to eliminate them in time with the assistance of suitable service robots for inspection. Service robots for use in piping systems are segmented robots equipped with wheels or tracks for the flow of internal oil, gas or wastewater, industrial or air ducts [21-23]. In addition, service robots for inspection help rapid detection of problems within piping systems, such as weld failures, corrosion, erosion, fractures, deposition, loose parts, faulty internal coatings, etc. Sewage service robots can clean pipes with a diameter of 200 to 600 mm, which are inaccessible to people. In order for the piping system to be constantly in function, it is necessary to have planned maintenance activities in which the elements of the system are changed or replaced according to predetermined schedule, in order to avoid frequent disruptions. Robots involved in the production processare cost-effective because they work throughout their service life, while control service robots differ from other robotic applications. If used in maintenance, especially in the nuclear industry, they can pay off during a single use, because by using a robot the nuclear plant avoids shutting down or continues to operate during the maintenance time. Depending on the dimensions and purpose of the piping system, the designs and constructions of service robots are customized so that we have many different robot constructions offered by many companies in the world. Due to limitations, we will only illustrate certain constructions and purposes of service robots for inspection and maintenance of piping systems.

Carnegie Mellon University (CMU) and the National Robotics Engineering Center (NEREC) with the support of the Gas Company (NGA), designed a new generation Explorer-II (X-II) service robotic system capable of inspecting pipeline control systems intended for pressurized gas [24,26]. The electronic architecture allows GPS to locate defects during pipeline inspections and quickly take action to repair anyerrors. The service robot, called a robot train, is made up of the module shown in Figure 4. Using a combination of its built-in drive elements and steering joints, the Explorer is designed to travel through straight pipes and reduction of pipe diameters, elbows, sharp curves and T-curves. The system is sealed and purified, which ensures safe operation in a natural gas environment.

The Explorer service robot is a remote-controlled robot for inspection and control of low-pressure and high-pressure gas pipelines with battery supply. This technology has the potential to improve the overall safety, reliability and integrity of natural gas infrastructure by providing a state-of-the-art tool for inspecting almost all piping systems. This robot performs a visual inspection of long-range piping systems made of cast iron and steel. The operator controls Explorer wirelessly and can monitor pipeline images in real time. Service robot for inspecting and controlling piping systems has exceptional mobility and can move like a snake through pipes with its flexible body.

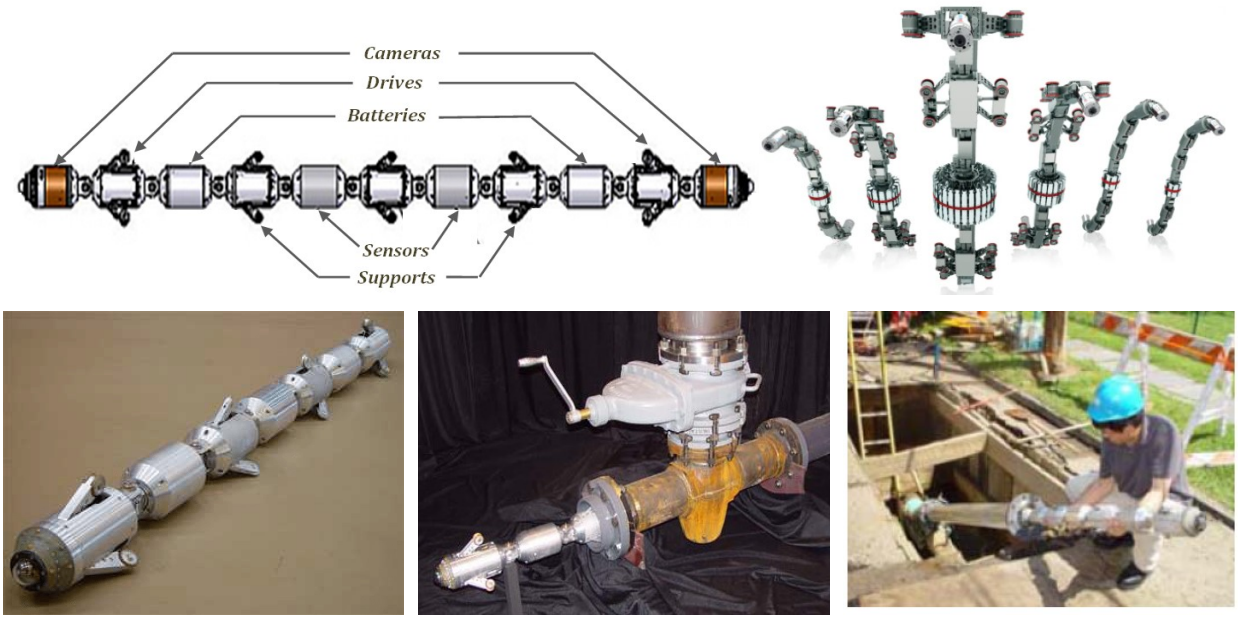

Figure 4 – Construction of the Pipeline Explorer service robot and implementation for inspection of the gas pipeline system [24-26]

The body segments contain batteries for power supply, a computer, two heads symmetrically placed with cameras and two connectors for operating elements, while the module allows the robot to move arbitrarily. The ball joint has three degrees of variation and is located between the drive units. Highly integrated electronics use a digital processor signal that controls the motor and gives accurate angle calculations.

Service robots for inspection and control of piping systems are reliable for inspection of corrosion, cracks and other types of defects, the detection of which avoids severe and expensive accidents. The service robots are designed so that different types of sensors and cameras can be placed on it, which can be integrated into the robotic navigation system.

Large electricity producers want to be competitive in the market. Their goal is to extend the service life of generators, turbines, boilers and pressure lines. They can achieve this only through inspections of the specified equipment, detection and elimination of defects. Until now, this was achieved manually with experts in the field. In recent years, with the development of robotic technology, this is achieved by service robots that perform measurement, imaging and scanning of surfaces. The advantages are great because we are able to inspect even those surfaces that are inaccessible to humans.

The service robots are designed so that different types of sensors and cameras can be placed on it, which can be integrated into the robotic navigation system. Figure 5 shows the various constructions of service robots for inspection and control of both piping systems and plants that are dangerous to the health of workers, such as nuclear plants or plants for the production of electricity such as generators, turbines, boilers and pressure lines. The main goal is to extend the service life of the plant, which can only be achieved through inspections of the specified equipment, detection of defects in time and their elimination.

Figure 5 – Different constructions of service robots for inspection and control of piping systems [24,27,28]

CONCLUSION

Service robots have already found application in inspections and maintenance, where human potential is replaced and where human presence is disabled. They have application in places where movement is disabled and hindered, such as testing piping systems underground and above ground. There is also a wide application of service robots

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in the branches of inspection and maintenance in which working conditions are dangerous to humans, where high temperatures are developed and where the concentration of substances dangerous to human health is increased, such as production and casting of metals, glass and ceramics, processes that include high pressure painting, welding, sanding, polishing, etc.

The trend of application of service robots for professional use is growing on annual basis, by an exponential function. This growing trend is expected in the coming years. There is also an increasing trend of service robots used for inspection and control of various systems, especially piping systems which humans cannot physically inspect. This growing trend is due to the implementation of basic technologies of Industry 4.0, whose aim is to have information about the operation of a system at all times. Various robotic systems have been developed for inspection and examination of piping systems and plants that are dangerous to workers' health. Service robots are tele-controlled by tracking or rolling of a moving platform and transmitted by a camera, sensor or simple tools.Most service robots for inspection are intended for tanks, piping systems for all media (water, gas, fuel, oil, etc.), for inspection of ventilation openings and pipes of air systems, sewer systems, nuclear plants, or work in aggressive environments. It is expected that the development and application of service robots for inspection will continue to grow in the future.

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