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Current and Future Research Focus on Inspection of Vertical Structures in Oil and Gas Industry

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Abstract: Regular inspection of oil and gas installations are vital for production, maintenance, safety and environmental impact assessment. Due to complex set-up and hazardous operation environment, the inspection, maintenance and repair (IMR) operations as considered as an inevitable task in oil and gas industries. Integrating technologies from the field of robotics, sensing and process control will be a decisive step in digitalization of oil and gas industry. The traditional vertical structures inspection system uses rope access, scaffolds, telescopic elevation platforms supported by cranes and manned helicopters. The challenges faced by conventional techniques are the construction of scaffolding, sending inspectors into dangerous and fatal environments, shutdown of plant operations etc. that has financial burden on the plant operating cost. Introduction of robotic technologies such as wall-climbing robots, Unmanned Aerial Vehicle (UAV) and wall-climbing drones, provides a possible solution for these challenges by increasing the efficiency, reducing the risks and lowering the cost of IMR tasks. The current research focus in this field is to automate and improve the inspection and testing capabilities of these systems. This paper presents the state of art of current scenario and future research focus on vertical structure inspection in oil and gas industry.

Keywords: Vertical structures, Oil and Gas industry, Inspection methods, Unmanned Aerial Vehicle, Wall climbing drone

1. INTRODUCTION

With increase in urbanization and industrialization, demand for oil and gas is expected to grow at a relentless pace in forthcoming years. The critical functions of an oil and gas industry are asset management, monitoring of production performance, safety and environmental compliance, overall integrity, and several other factors. When focusing on the sustainability and resource efficiency in the oil and gas industry, closer attention should be paid to the reliability and serviceability of existing structures to extend their lifetime. This requires more sophisticated and effective methods for inspection and monitoring of structures, in order to assess their structural state and thus trigger repair and rehabilitation efforts.

The planning and execution of Inspection, Maintenance and Repair (IMR) activities in oil and gas industries are costly and time consuming due to its complex set-up and hazardous environment. The maintenance and surveillance activities should be done carefully to avoid leaks, unplanned shutdowns and production outages. Therefore, while performing the IMR tasks, various components have to be shutdown partially or completely to avoid damages to the inspection equipment and injuries to the maintenance personnel [1]. There are continual requirement of close visual inspection of plant and other structures in both onshore and offshore oil and gas industries. The routine inspection, maintenance and cleaning of these infrastructures involves number of manual operations which are dangerous for skilled workers. Rope access inspection, construction of scaffolds and usage of manned helicopters are some of the conventional methods employed to inspect and monitor the high-rise structures like flare stacks, storage tanks, cooling towers or live systems in an oil and gas industry. The various challenges in performing conventional manual inspection methods are (i) Working personnel has to climb the high-rise or live systems to conduct the inspection tasks. (ii) Inspection sensors need to be carried in hand by the operator while accessing the structures at height. (iii) Close visual inspection is not always possible on live systems. (iv) The manual inspection methods are time consuming, labor intensive, inefficient, requires high skilled operators and involves high cost and risk factors.

The above-described limitations in performing conventional inspection tasks can be overcome by introducing robotics and drone technology in oil and gas industries. Industries are now using climbing robots and unmanned aerial vehicles (UAV) to carry out the inspection tasks in parallel with the conventional methods. A certified UAV pilot is required to navigate the UAV along the structures to be inspected and to perform IMR tasks. The gathered information is then analyzed by an experienced inspection engineer to identify the possible anomalies. The oil and gas industries are now focusing on the development of an autonomous inspection/testing method to carry out the inspection tasks in high risk and hazardous areas. The aim of researchers is to develop a UAV, that can (i) autonomously identify the structure to be inspected, (ii) automatically generate the tracking trajectory and (iii) to

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navigate along the identified structure. The real-time data collected by the UAV should be analyzed autonomously to detect the anomalies. The autonomous navigation and inspection method using UAV does not require a skilled operator and can be used for 24/7 inspection of vertical structures efficiently and safely by reducing the operational cost and time in both onshore and offshore oil and gas industry. Various inspection methods that are used in oil and gas industry is explained in section 2. The research focus in the field of robotic inspection is described in section 3 and followed by the conclusion in section 4.

2. CURRENT INSPECTION METHODS

The oil and gas industry operates according to stringent standards that primarily strive to keep equipment running efficiently while maintaining workplace safety. Routine inspection has significant impact on the maintenance cost throughout oil and gas plant's operating period [2]. The complex set-up and hazardous environment of an oil and gas industry increases the risks and challenges in performing IMR tasks. The employers have to put themselves at risk, any time they want to inspect the high-rise vertical structures like flare stacks, storage tanks, boilers, cooling towers, chimneys and other confined spaces. Based on the inspection method, current inspection methods employed in oil and gas industry can be divided into (i) Manual inspection and (ii) Robotic inspection.

2.1 Manual Inspection

The manual inspection activity involves detecting defects and making a judgment based on the type of defect, whether to accept, reject or rework the part. In manual inspection, the human efforts are being used in the entire inspection process like search, fault recognition and finally the decision making [3]. The inspectors who are responsible for performing the IMR operations are currently using the following procedures to access the vertical structures in the oil and gas industry.

2.1.1 Installation of scaffoldings around the structure

The height of a typical flare stack system may vary between 70 to 90 meters and the diameter of the storage tank varies from 5 to 40 meters [4]. Therefore, the main problem with the traditional access by using existing ladders and platform is the limitation of the area to be inspected [5]. The use permanent scaffolding system are very costly and require prolonged stoppages to assemble/ disassemble them. If installed, the scaffolding systems are very convenient for performing inspection and repair tasks. Tubular scaffoldings are normally installed for the inspection of small flare stacks height less than 40 meters.

2.1.2 Rope access techniques

High-rise structure inspection using rope access techniques are currently considered as more advanced and safe, allows expert personnel to gain access to any part of the flare stack with limited means and great speed. The speed and versatility are the main advantages of rope access inspection whereas the heavy load of testing instruments that has to be carried by the worker for inspection is a serious drawback of this system. This system is mostly used for Non-Destructive Testing (NDT) purpose [5].

2.1.3 Elevation platforms supported by cranes

Oil and gas industries are also using elevation platforms with telescopic arm or baskets supported by cranes for conducting IMR operations. Such platforms are useful to perform maintenance tasks. On the other hand, utilizing this system for NDT techniques are expensive as the cranes have certain limitations in terms of access and reach because of the existence of guy wires of the flare stacks.

2.1.4 Manned and remote-controlled helicopters

Live flare stack inspection is not possible for a human operator due to the extreme heat generated. So the above mentioned inspection methods, which involved more human activities has to be conducted during partial\full plant shutdown. Helicopter based inspection methods are then introduced to inspect the structures like flare stacks and storage tanks from a distance. The manned and remote-control helicopter inspection methods are used to identify any issues within the flare system that may require maintenance but are not identifiable from ground level. Manned helicopter inspection can be performed when a flare unit is in stable operation and atmospheric conditions are favorable, i.e. little to no wind, and clear skies. Depending on the complexity of the flare system, this inspection can take 30 minutes to two hours of helicopter airtime. The inspection includes an evaluation of all photos and videos while the helicopter remains on-site to determine if further shooting is required [6]. This particular type of inspection method was not universally accepted due to concerns of placing helicopter personnel in hazardous environment. Tight coordination between operations and maintenance is critical to minimize the exposure of the manned helicopter inspection team to potential hazards. The remote-controlled helicopters were limited by the quality of the photographic equipment and the availability of experienced fliers. The helicopters are expensive and the concern over losing control while airborne over a process area that requires experienced pilot and fliers. The high capital and operation cost were also considered as a serious limitation of manned helicopter based inspection.

The above mentioned manual inspection methods for vertical structures like flare stacks, storage tanks, cooling towers, boilers etc. are considered to be risky and inefficient because (i) the presence of toxic fumes from the facilities, which can also cause explosions (ii) the inspector has to use a variety of climbing/suspension equipment for inspecting vertical structures and can lead to fall and accidents (iii) hostile environment and unfavorable weather become a hindrance for the testing process (iv) the manual inspection sometimes need full/partial shutdown of operation to fully analyze the component which leads to loss of production and revenue. These limitations in manual inspection leads to the development of robotic solutions for the vertical structure inspection in oil and gas industry.

2.2 Robotic Inspection

As the review of manual inspection indicates, conducting manual IMR operations in dangerous and hazardous environment requires great amount of work force and time for the non-productive works. As the manual inspection methods are slow and error prone, a highly skilled operator with expert working and decision making skill is required for conducting these tasks. Attempts to improve the efficiency of inspection task lead to the use of robotic technology for IMR operations in the oil and gas industry. Conventionally, the manual inspections are done either at scheduled time or whenever an accident has occurred. The manual inspection can be prohibitively time consuming and expensive, forcing the oil and gas companies to complete their facility inspection only when required by law. The major benefits with the robotic inspection method is that inspections can be conducted more frequently due to their low operation cost. The robotic inspections can be conducted either in remote-operated or as fully autonomous manner. In both cases, the inspector does not need to be on-site to inspect the entire facility much faster and effectively than the conventional methods. The robotic solutions used by the oil and gas industries for their vertical structure inspection are:

2.2.1 Wall climbing robots (WCR)

In recent years the maturity and stability of climbing technologies have resulted in increasing number of climbing robots in industrial applications [7]. Automating the manual inspection tasks with WCR could permit large savings in monetary and human cost. Robotics and mechatronics researchers have been demonstrated a variety of climbing robots for vertical infrastructure inspection. Typically, these robots are inspired by reptiles, mammals and insects and their type of movement varies between sliding, swinging, extension and jumping. The design and control complexities involved in developing locomotion for the WCR on vertical surfaces like stability, flexibility, surface contacts issues, power consumption, overheating of motors, and climbing between adjoining surfaces etc. limits their ability for most of the practical applications.

WCR systems that have been developed for external inspection of storage tanks are mostly tethered and semiautonomous remote controlled systems and hence reduces the flexibility of the system. The MATS robot has 5 DOF and a symmetrical mechanism that showed good mobility features for travel, however, it requires special docking stations to hold itself. A prototype model, Walloid was designed for offshore oil and gas facility inspection that can choose the adhesion method increases its robustness and flexibility needed for industrial applications [8]. A bio-mimicking robot, Sticky Bot, has a hierarchical adhesive structure under its toes to hold itself on any kind of surfaces [9]. To evaluate the degree of corrosion of the metal plates, periodic inspections are done by using Non-Destructive Test (NDT) equipment that can measure the thickness and evaluate the integrity without causing any damage to the area under inspection. A climbing robot for corrosion monitoring of reinforced concrete structures such as cooling towers are developed by combining a vortex adhesion mechanism with a wheel electrode sensor for potential mapping of concrete structures [6]. These robots could not only replace a worker undertaking risky tasks in a hazardous environment but also increase the efficiency of such tasks. However, they require complex mechanical designs, special materials and complicated dynamics analysis. As the size of WCR is very less when compared to the size of the structures to be inspected, the possibility to inspect the whole surface area of the tank without any omits will be very less. And also, their application is limited to specific type of structures, such as cylindrical-shaped structures. UAV platforms are a feasible alternative to achieving the same goals as climbing robots and involve a much simpler mechanism.

2.2.2 Unmanned Aerial Vehicles (UAVs)

The introduction of drone technology in oil and gas industries revolutionized the inspection of high-rise structures by offering a more long-term and sustainable option compared to other available methods. Drone inspection involves capturing, storing and analyzing large quantities of data that are gathered during a drone flight. Avoiding climbing utilities such as roping systems, scaffolds etc. flying inspection robots can provide a means of efficient and frequent facility health monitoring without endangering inspection staff or extensively impeding plant operation. Inspection drones fitted with visual cameras and Infra-Red (IR) cameras can help in implementation of RBI inspections of Oil & Gas assets under API RP-580 as well as Fitness-For-Service Analysis under API 579-1 / ASME FFS-1. Inspection Drones which are designed for operations in closed or congested spaces can prove extremely advantageous for inspection carried out under piping (API 570-Piping Inspection Code) and tankage (API 653-Tank Inspection, Repair, Alteration and Reconstruction) [10].

First fully functional UAV to inspect plant assets, such as flare stacks, were at the UK onshore oil refineries in year 2010. With this technique, for the first time operators got the chance to understand condition of their equipment before any kind of shutdown, and without exposing work personnel to risky environment [11]. This system has enabled engineers to continuously monitor critical components located at difficult height in plant structures, such as chimney stacks, ducting, pipe racks, and vents, while allowing them to prioritize maintenance, relocate budgets, defer shutdown, reduce the time for turnaround and order replacement parts before turnaround. While performing the inspection tasks, the UAVs are operated manually by a certified pilot to navigate the UAV along the structure to be inspected and the data obtained from inspection sensors such as HD camera, thermal camera, hydrocarbon leak detection sensors etc., while flying is then analyzed by an experienced inspection engineer to identify the faults like hairline cracks, corrosions, gas leakage etc. Since, the drones can carry cameras with 4K video recording and optical zoom and various other sensors, there is no need to get the drone too close to the live structures or other risk areas.

The drone based inspection in oil and gas industry is getting more attention due to (i) its ability to inspect areas that are potentially hazardous (ii) cost effective as well as efficient inspection method (iii) its ability to inspect a large area in less time and (iv) the operation of the drone does not require a highly skilled inspector. Many third party companies are now offering the UAV inspection solutions for the oil and gas industries.

3. RESEARCH FOCUS IN ROBOTIC INSPECTION OF VERTICAL STRUCTURES

Advancement in sensor technology, communication and robotics, bridge the gap between manual control and vehicle autonomy. Development of new prototypes and automating the existing technologies extends the inspection capabilities in oil and gas industries. As the UAV inspections are safe, accessible and cost effective, through frequent inspections, the oil and gas facilities can be kept safer without investing much in costly and disruptive in-person examinations. Through better technology, the oil and gas companies will be able to improve the safety of their facilities and focus on optimization and revenue generation. The wide acceptance of UAV based inspection motivates the researchers to contribute and continue to work more in this field. The main research focus in robotic inspection are:

3.1 Wall Climbing Drones

The researchers have developed several robots for wall crawling, yet there is no guaranteed solution. One of the critical reasons why existing wall-crawling robots have not been available in the field is the risk of accidental fall due to operational failure from the harsh environment, like strong wind and the surface's unpredictable condition. Then the researchers developed wall climbing robot that can approach to any place of the structure to be inspected by flying and stick to the target place with pose change and perching mechanism. Wall climbing mechanism of the aerial robot is based on a combination of the thrust force and wheel drive force by maximizing friction between the wheel and the surface [12-13]. When friction coefficient is higher than 1, the robot can attach to the vertical surface with the thrust force towards the wall. Since the robot can stick to the surface, it can perform close inspection and maintenance of the structure.

A wall-sticking drone that is capable of performing NDT testing was developed for the first time [14]. The drone uses a combination of the thrust force and electromagnetic force to press the sensor probe on the metal surface. The ultrasonic probe attached to the extended arm induces a normal beam ultrasonic signal that travels through the surface and subsurface, and the reflected signal from the back surface is detected by the probe and is converted to a digital reading of the thickness of the part underneath the probe. United Aerobotic had designed MAGNEBOT, capable of landing vertically on a furnace waterwall and can turn off its rotors for energy savings while continuing to operate the camera and lighting system within high-priority inspection areas. Once inspection is complete in a particular region, blade rotors can be reenergized for effective and smooth wall departure. Then the drone can be flown to another region for continued inspections [15]. VertiGo is a wall-climbing robot that is capable of transitioning from the ground to the wall, created in collaboration between Disney Research Zurich and ETH [16]. The robot has two tiltable propellers that provide thrust onto the wall, and four wheels. One pair of wheels is steerable, and each propeller has two degrees of freedom for adjusting the direction of thrust. By transitioning from the ground to a wall and back again, VertiGo extends the ability of robots to travel through urban and indoor environments. The use of propellers to provide thrust onto the wall ensures that the robot is able to traverse over indentations such as masonry. The choice of two propellers rather than one enables a floor-to-wall transition – thrust is applied both towards the wall using the rear propeller and in an upward direction using the front propeller, resulting in a flip onto the wall.

SCAMP is a type of wall climbing drone which can perch and climb on unprepared surfaces such as concrete and stucco walls [17]. CAROS, developed by KAIST also has an advantage in that it can restore its pose after an accidental fall due to an unexpected disturbance [18]. FAROS is currently developed based on CAROS to overcome narrow or destroyed spaces caused by fire. For autonomous navigation, the FAROS estimates its pose by utilizing a 2D laser scanner and an IMU sensor installed in FAROS. With the localization result and a thermal imaging camera installed on FAROS, the robot can also detect and localize the ignition point by dedicated image processing technology. These technologies are expected to be applied to the inspection or maintenance of structures and objects in remote or inaccessible regions. The limitation of wall climbing robots is safety, localization on the structure and limited payload capacity.

3.2 Autonomous Drones

Now, the researchers are focusing towards the development of an autonomous drone that can perform inspection tasks by identifying the structure to be inspected, navigate autonomously along the identified structure, collect and analyze the data collected and locate the fault locations autonomously. The UAVs can be equipped with an array of sensors including HD camera, Infrared camera, Thermal camera, LiDAR, gas detection sensors, various NDT testing equipment that facilities its ability of autonomous navigation and data collection.

3.2.1 Structure identification & autonomous navigation

Autonomous navigation of aerial vehicles and structure identification in GPS-denied environments has recently gained attention in the robotics community. A Vertical Take-off and Landing (VTOL) platform based pole-relative navigation system using position and visual based servoing and shared autonomy was developed for the aerial inspection of vertical structures [19]. The pole-relative navigation increases the autonomy of the system and facilitates the use of shared autonomy where the operator is relieved of the cognitive load of controlling all degrees of freedom. The researchers are developing vision based navigation system along with the onboard sensors to provide a suitable solution for target tracking in GPS denied environment. Indoor navigation of quadrotor was developed using a laser range sensor [20]. However, the requirements, imposed onto the system by a localization based on scan matching along with altitude measured by a deflected portion of the scan, are not met in most industrial environments. Approaches using an RGB-D sensor instead of a laser scanner [21] do not share the same constraints on the structure of the environment, but are only applicable to indoor operations. The advanced image processing algorithms such as Scale-Invariant Feature Transform (SIFT), Speeded up Robust Features (SURF), Simultaneous Localization and Mapping (SLAM), Parallel Tracking and Mapping (PTAM) etc., are widely used by the researches for the accurate target identification and tracking in outdoor operations. An autonomous features based target identification method was introduced using SURF detector [22]. Autonomous pipeline detection and tracking algorithm [23] was successfully implemented using canny edge detector and Probabilistic Hough Transformation for horizontal onshore oil and gas pipeline structures [24-25]. These algorithms can be modified and used for autonomous vertical structure inspection in oil and gas industry. It is clearly seen from the review that even though many attempts are continuing to automate the vertical structure inspection, no fully autonomous vision based inspection system that is capable of detecting the faults has been successfully developed yet.

Deep learning algorithm especially convolutional neural networks have greatly improved the performance of visual recognition systems for many advanced applications such as self-driving cars, image search, and image understanding. It provides a general method for automatically learning features, which can dramatically reduce the effort in hand-designing solutions for every sub-task in power line inspection. The generalization ability of deep learning opens great possibilities for vision based inspection since a model trained for one task with a very little effort in fine-tuning can be adapted for use in many other related tasks [26]. The deep learning algorithm used for autonomous vision based power line inspection [27] can be used for autonomous vertical structure inspection with required neural network training.

3.2.2 Autonomous data collection and analysis

Autonomous aerial inspection systems must be developed which possess the capability of autonomously scanning along flat or curved surfaces, keeping the inspection camera aligned perpendicularly to the inspected area while avoiding possible obstacles along the way. The required inputs from the operator must be limited to simple directional commands and high level instructions. To provide the means for visual inspection, live images must be transmitted to the operator's base station and stored for future analysis. Computer vision techniques allow 3D reconstruction of an object from multiple images, after which it can be viewed from a variety of angles. The functionality of 3D mapping the scanned surface is desired to localize damages found during the inspection [28]. Once a 3D model of a structure exists, the location of damages and repairs may be tracked for future servicing periods using a servicing history. Such models would allow better planning for current or future maintenance sessions and thus increase the efficiency of the inspection of vertical structures in oil and gas industry.

4. CONCLUSIONS

This paper presents a review of current inspection scenario and the future research focus on vertical structure inspection in oil and gas industry. The challenges to be faced during the development of autonomous inspection system for oil and gas industry may include the regulation around the machine learning systems used for automated flight, payload limitations, manage the transition towards effective solutions regarding contingency and failure management, cyber resilience in order to mitigate against deliberate use of drones.

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