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Development of a Multi-robotic System for Exploration of Biomass Power Plants

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Abstract—**Biomass Integrated Gasification Combined Cycle (BIGCC) is a power generation technology which has been vastly used in past years. Maintaining those power plants are very crucial due to having various risk of hazards. In order to increase workers safety and reduce property losses, common faults which are reported in BIGCC based power plants were investigated in this paper. Also, a fault detection methods using multi-robot system was proposed. Therefore, autonomous group of robots were used for achieving continuous inspection in BIGCC power plants. The inspection scenario and implementation of the proposed scenario were conducted with simulation software, V-rep. Two types of mobile robots, ground and flying robots, have been deployed.**

Index Terms—**Exploration, Autonomous System, Mobile Robots, Extreme Environments**

I. PURPOSE OF THE RESEARCH STUDY

Inspection using robotic platforms has become an important research topic in recent years. Particularly, some patrolling robots have been developed for smart industry in petroleum [1], chemical industry [2], power plant [3] and other applications [4]. With regard to single robot inspection, the robot for visual inspection of nuclear plants were proposed in [5] [6]. The proposed robot can reduces human involvement in inspection of nuclear radioactive area. In a recent study [7], an aircraft fuel tank inspection robot was developed. It decreases the workload of aircraft crew and improves the maintenance efficiency. Although using single robot for inspection is an efficient approach, multi-robotics has shown better performance to solve exploration tasks in complex and unknown environments [8]. As an example, an inspection of jet engine turbine using miniature swarm robots were proposed in [9]. In another study, an application of swarm robotics in crops inspection for precision agriculture was proposed in [10]. The custom robotic systems can be the one main reliable solutions for industry.

BIGCC is an advanced power system to extract energy from renewable biomass sources. There are nearly 2000 biomass power plants producing a total of 22.5 GW in over 40 countries [11]. BIGCC usually containing 13 key sub-systems as listed in Table I. It can achieve zero emission to offer good performance on environmental protection [12]. However, several flaws remained in BIGCC. The gasification is a dangerous process and it may pose issues of Occupational Safety and Health (OSH) for workers and environmental damage [13]. In August 2017, a man had multiple injuries of serious burns after an explosion in a gasification plant [14]. Six weeks later, two men were badly hurt in another gasification plant again [14]. In addition to the reported accidents, various risks exist in the power system. To identify the dangerous causes of BIGCC power plant, some general faults of power plants were listed in Table I. These issues of the power system have drawn a great risk to the 1.2 million workers [15]. Numerous people have to face a series challenge on their works for each family's well-beings.

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Monitoring of power system equipment is an indispensable process for their sustainability and continuous maintenance. Some invention has been proposed and implemented. Wall-climbing robot was proposed for inspection of nuclear plants equipment [16]. Application of robots for tank inspection in power plant was proposed in [17]. Recently, a multi- function pipe inspection robot was proposed in [18]. These robots have helped engineers for inspection and maintenance in some extent. These inspection robots were most suitable for static environments and it has to cooperated with human operator. An advanced way for monitoring dynamic power system is using an automated guided vehicle (AGV). It have been utilized to follow a certain path [19] and integrated sound, light, electricity and computer [20]. In addition, another forward research that is using robot service to renewable wind- farm was developed in [21].

In summary, inspection using mobile robots still has a room for improvement in the dynamic power system. Single robot deployed for large scale energy system has limitations by its ability, such as running speed, power capacity of unmanned aerial vehicle (UAVs), multi inspection tasks, inspection frequency etc. Multi-robotics system has strong robustness which made robotics system becomes flexible and scaleable. However, inspection using autonomous multi-robots for the renewable energy system is demanding research area. The project has broad prospects and generality that is focused on to solve real-world problems by integrating robotic technology into the renewable energy system, it also contributes to the body of knowledge in the multi-robotics technology. This work aims at providing a reliable autonomous multi-robot system to carry out continuous patrolling tasks, specifically to help to inspector keep away from hazard areas of a power system. The proposed multi-robotic solution in this study will be able to cover inspection tasks of full-scale biomass power plant.

II. METHODOLOGY

A. Research Question

BIGCC technology has several immaturities as listed in Table I. Any faults in BIGCC power plant will result in

TABLE I
LIST OF SUBSYSTEMS AND GENERAL FAULTS IN BIOMASS-IGCC

BIGCC-Subsystem	Functionality	Problem, Running Condition	Consequence
Biomass Raw Material Handling System	also called pulverization stage, which convert the raw biomass material to the small pellets	dust explosions, self ignition, off-gassing of bacteria, fungi	fire, explosion, worker fatalities, loss of production, poisonous, power plant destruction, operator OSH, gas/steam turbine or generator damaged, electricity black-out in large scale, terminal user unsatisfied, power plant maintenance
Biomass Storage System	for storage the wet biomass pellets, general its a circular shapes tank.		
Biomass Feeding System	for delivery of the treated pellets to the carbonization system. Typically, it's a closed screw feeder.	noise	
Carbonization System	remove the different moisture content (MC%) from biomass pellets for reduce the gasification system primilary energy cost.	self ignition	
Air Booster System	pump the compressed air to gasification and gas power system.	high temperature, pressure	
Gasification System	which is the key part of the BIGCC power technology, the function of gasifer is transfer the solid fuel to gases fuel after a series gasification process.	syn-gas leakage, explosion-prone	
Tar Remove System	for remove the tar from syn-gas, this process will start after gasification transfer process.	high temperature, pressure	
Syn-Gas Purification System	remove the ash and impurities from syn-gas. such as: C, SiO2, COS, NH3, H2S etc.	combustible leakage	
Gas Power System	for electricity generation, which is decide the entire power system energy utilization factor.	generator excessive vibration and overheating, tube corrosion, leakage, noise, output voltage level over accepted level	
Steam Power System	Heat Recovery Steam Generator (HRSG) system was the main part of steam power system, which is used for recovery thermal energy from hot flue-gas, this process is for highly system net thermal efficiency.		
Heating System	recovery the bleeding from power cycle for supply hot water to terminal user.	output water temperature higher/lower than accept level	
Refrigeration System	recovery waste heat from power cycle for support cold requirements.	refrigerator fault	
Back-up System	support power to user when the BIGCC system maintenance or fault happening.	back up system start time delay	

injuries to workers and property losses. It is essential to provide continuous monitoring of the facilities using intelligent devices. Multi-robotic solutions will improve the performance of monitoring for this kind of long-term exploration of large facilities.

B. BIGCC Scenario Development

BIGCC system generally containing different sub-systems, the detail was as listed in Table I. Each sub-system have been built in V-Rep software. The primary model work was as shown in Fig. 1. The BIGCC model developed from raw biomass material handling process, main energy converting process, power generation cycles etc until the electricity output processes. General and faulty, two modes will be conducted in to the experimental. Such as: steam leakage, tube overheat, switching operation, parameter calibration with control center, self ignition, cable trench inspection etc.

C. Multi-Robotics System

1) Flying Robot – Trailbreaker: Trailbreaker is a four-axis UAVs robot as shown in Fig. 2. The Trailbreaker robot was allowed in six degree of freedom (DOF) flying. For gathering data from BIGCC, sensing equipment will be attached to group of Trailbreaker robots.

Energy radiation around everywhere in BIGCC, which provides good opportunities for monitoring the temperature of each subsystem. While, each sub-system of BIGCC running in a constant state. The temperature values of each pipelines or subsystems will exist in a constant value. Thermal camera will be employed into the robot system for detect the energy emission of BIGCC. A thermal map therefore can be generated in time, while a set of normal threshold value will be added in the robot system. Thus, monitoring of temperature fault will be achieved Trailbreakers. In another hand with regard to others issues of BIGCC, for example leakage, open flames or some instrument parameter reading etc, is indispensable tasks to the inspection robot as well. Additional vision system will be equipped on-board of Trailbreaker robots for guarantee more redundancy of inspection process.

2) Ground Robot – Wheeljack: Wheeljack, is an unmanned ground vehicle (UGV) robot as shown in Fig. 3. The Wheeljack is designed to cover the missing inspection points from Trailbreaker. In the other hand, the main contribution of Wheeljeack is fix general issues of Biomass-IGCCs.

Road boundary detection and obstacle avoidance are essential task to the robot inspection. Unknown environmental and multi obstacles of BIGCC has made inspection process more complexity. A high-resolution camera and radar system has designed and employed in Wheeljack robots. The Wheeljack robot was able to directly measure the range, velocity, and azimuth angle of obstacles [22]. With these equipment deployed, the inspection of robot system performed with excellent quality on problem judgement. Different accessories will be employed with regard to debug process of Wheeljack, such as a cooling tank for overheat problem, a fire extinguisher for ignition or an additional manipulator for transfer the wounded operators, etc.

3) Multi-Robotics system control mechanisms: A hybrid architecture (combine centralized and distributed) will be

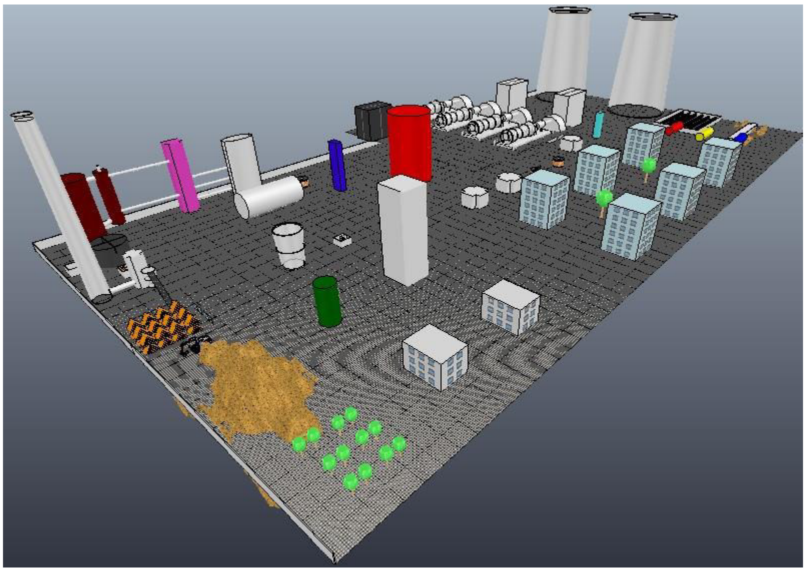

Fig. 1. A model of Biomass-IGCC Power Plant developed in V-rep

attempted to deployed in Heterogeneous robot system. The Trailbreaker, Wheeljack and base station will cooperate with each others to conduct the exploration tasks. The tasks for robot system will be classified to different priority levels. Trailbreaker and Wheeljack will be allowed to command each other. Wheeljack collective behaviours will judged by Trailbreaker. Feedback mechanism will be deployed when an unreasonable command received. Each robot will broadcast a signal of itself current status to its own team, as well as around robot. The signal information, such as current position, inspection missions and priority levels, fault information, state of power etc. Additionally, heterogeneous robot system will be separated into different small teams. Wheeljack and Trailbreaker will be treated to different agent groups. Each groups will performing inspection in autonomous and worked at a specified area.

D. V-Rep Implementation

V-Rep is a free simulator for education with versatile and scaleable framework for modelling robotics. It is vastly used in the academic as well as industrial applications [23]. In this project, V-Rep will be employed for carrying out the entire system modelling work. The simulation process will be split into four steps:

- Building a biomass power plant model. This will be achieved by utilizing the various physics and graphics libraries in the V-Rep. Some of sub-systems will be specially designed compared with real case, for example ignition of storage system, feeding water temperature of power systems.
- Building and control heterogeneous multi-robot model. To utilizing the V-Rep robot simulator and controller. Such as a robot motion control: (a) define the desired robot position (b) using V-Rep to calculate the kinematics for each motor (c) assigning the calculated motor positions to be used as target positions by the dynamics module [24]

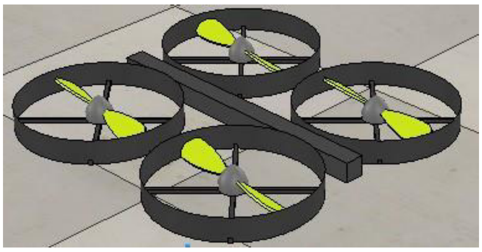

Fig. 2. A model of Trailbreaker Robot

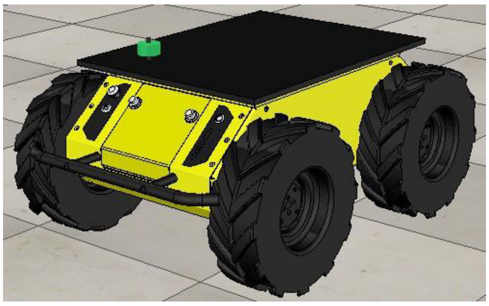

Fig. 3. A model of Wheeljack Robot

- Group robot inspection synergy design. This relative on architecture, communication, the collective mechanism (multi-task allocation, multi-robot path planning), collective localization and mapping and target following etc. More detail can be check in [24]
- The entire system modelling and implementation. Calibrating the power plant and robot model to general states. Dynamic experimental of proposed system under different modules calling. The modules detail can be found in [23]

III. Research Limitations

- The representative of data has various limitations, e.g. simulation random fault cannot represent the real situation.
- A large scale scenario is difficult to develop in simulators, e.g. details may be ignored or results may contain unrealistic values.
- In a real-world experiments, robots are not be able to conducted complex task probability due to their processing or communication limits.

IV. Originality

The project has broad prospects and generality that is focused on to solve real-world problem by integrating advanced robotic technology in the renewable smart grid. Three originality details are as follow:

- This project has a wide range of applications. The proposed robot system has ability to performing inspection in any power or similar power plant, such as gas, thermal or nuclear.
- Monitoring a large scale facility using a group robot. This is inspired by the collective behaviour of ants or honeybees. This project will improve the inspection performance, and propose new applications for group robotic systems
- Integrating heterogeneous multi-robot and smart renewable grid together. This project will help in building the first world smart autonomous renewable energy system

V. Further Works

Two objectives will be the main research direction of this project:

- Exploration of a BIGCC using the heterogeneous multi-robot system
- Development of collective control mechanisms for multi-robot system

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