A heterogeneous autonomous collaborative system for powerline inspection using human-robotic teaming

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***Abstract*—This paper explores a novel system architecture of heterogeneous collaborative system for powerline inspection using human-robotic teaming. The research uses Quanser's Autonomous QCar and QDrone to demonstrate the results. This heterogeneous powerline inspection system consists of three separately controlled elements that work collaboratively within a centralized controlled space and those individual elements are as follows: 1) A control system operated by the human that takes cares of the Autonomous car and drone functionality, 2) An autonomous unmanned ground vehicle system that will take tasks from the human control system to drive through the path determined, and 3) An autonomous unmanned aerial vehicle system that conducts the powerline search and inspection within a specified range. All three systems operate together as one heterogeneous system, which demonstrates the application of human-robotic teaming. This paper will demonstrate how the proposed system architecture is constructed and the results obtained from it in an indoor environment is discussed.**

***Index Terms*—collaborative system, human-robotic teaming, powerline inspection**

I. Introduction

Using Unmanned Aerial Vehicles(UAV) like drones has proved to be a viable alternative method in conducting powerline inspection in combination with Intelligent automated systems[1,2]. Not only that with the use of several airborne sensors alongside the UAV's brought the capability for the drones to detect common faults, such as transmission line faults, damage of transmission tower, and loss of line equipment. This kind of approach eliminates the limitations in conducting powerline inspections like road distribution and geographical issues by significantly increasing efficiency and reducing the time and cost involved in a regular inspection. Another advantage of using a drone inspection approach is that there will not be any risk involved for the technicians and eliminates the need for facing complex environments and conducting dangerous operations. Due to these several advantages mentioned above, many companies are looking into integrating drones for powerline inspections[3,4]. One such instance, of a 60-mile transmission line inspection using a drone was successfully demonstrated by Ameren in November 2018 [3]. Another successful implementation of drones in inspections of transmission lines is Indiana Michigan Power(I&M) in Randolph county from January 2019 [5]. Apart from these there are several other instances that the companies used drones for conducting inspections of their powerlines[6].

However, even though various use cases show evidence of using drones in the inspection. Some obstacles prevent the wide adaption of usage of drones in powerline Inspection; such conditions involves hovering of drones at low altitude for closer inspection. In those situations, small-scale drones bring more versatility in obtaining accurate detection during the inspection. However, even in small drones, there is limited endurance and cannot inspect longer distances. Also, due to the limited battery power capacities on the drones, it is challenging to perform more extended inspection missions. In order to establish several ground stations for the communication to the drone, turns out to be an expensive task and is not practical. There is also a very high chance of experiencing the communication loss between the ground and the drone while performing the inspection. To address these issues that occurred during the time of inspection using drones, a novel system architecture for a heterogeneous autonomous collaborative system for powerline inspection with human-robotic teaming is presented in Figure1, which consists of a control and communication system that takes care of the QCar and QDrone functionality, from which the autonomous unmanned ground vehicle system QCar take commands to drive through the path determined to it, Once the QCar takes control of the path determined to it. The drone follows the QCar, and once the set location is reached, the QDrone will starts the inspection process by looking for any powerline that exists within the specified range. If there are any powerlines that exist it will start performing powerline inspection. To demonstrate this the paper is structured as follows. Section II. presents the Related Work, Section III. illustrates the proposed heterogeneous system architecture and the algorithms that are used. Section IV. talks about the testing of the proposed architecture in an indoor environment, and concludes this paper by, Section V. presenting the conclusion and future work that is going to be carried out.

II. Related Work

Power generation and distribution have been an area of concern for a while due to the rapid increase in electricity demand. Due to these reasons, many researchers have contributed to the planning an expansion of the power grid [7-10]. In order to assess the effects of the electricity market on profit, availability, and supply security, a model was developed by Sarica et al. [11]. From which it shows that there possess a critical challenge for the inspection of power transmission lines.

With that being said, many researchers in recent times has focused on finding more economical and efficient ways to conduct out powerline inspection. One early usage of a proposed system proposed by the Tokyo Electric Power Company proposed a mobile robot to detect 66KV Fiber Optic Overhead Ground Cables(OPGW) in 1991. This mobile robot can run on the OPGW and eliminate some of the obstacles, such as the counterweights and clamps[12]. Since then, the research has come a long way, and many studios have discussed hardware design and constructing inspection robot software; part of this investigation also focuses on the inspection robot's obstacle avoidance. One such example is discussed in [13]. Fast forward from the time of using mobile robots for detecting OPGW. In 2009, katrasnik et al.[14] surveyed the use of mobile robots in the inspection of transmission lines and discussed the inspection activities conducted with automated helicopters or flying robots. Another survey is conducted [15], which shows that this kind of inspection method will improve efficiency and reduce costs and shows the latest trends in robot transmission. Besides this, there are also studies conducted in database environments[16] and various detection methods using videos and images[17]. For effective monitoring and maintenance, Fan et al.[18] proposed a Multi-Robot Cyber-Physical System(MRCPS).

Recent developments in remote sensing and the use of Artificial Intelligence to automate tasks, the application of Unmanned Aerial Vehicles (UAVs) possess a massive opportunity in applications such as reconnaissance missions[19]. One main reason that UAV usage in the inspection of powerlines is receiving more attention is due to its low cost and high efficiency that can play a significant role in the inspection of bridges, cell towers[20,21]. Specifically, when about the field of electricity, drones have been used to inspect both transmission structures and powerlines [22,23], for which different kinds of inspection systems were designed for different platforms used. One such example of such systems would be an autonomous small helicopter platform that showcases both fixed-wing and rotorcraft UAVs developed by Hrabar et al. [24] exclusively for powerline inspection. Few other studies discuss large unmanned helicopters that can equip multiple sensors that track the powerlines automatically[25].

While using drones for inspection, accuracy is one of the essential factors, and there are some algorithms proposed that are mainly using images that are captured and able to recognize different objects of interest for classification and recognition tasks[26-30]. Vemula et al.[3] Furthermore, Martinez et al. [28] have combined classic computer vision and machine learning for autonomous aerial powerline inspection and localization of different components. In this paper, the authors utilized Reinforcement Learning, Deep Learning in the proposed powerline inspection system. From the above-related work that most of them are mentioned in one way or another related to hardware design or the flight control of the drone inspection. The inspection problem with respect to the transmission line with a heterogeneous autonomous collaborative system using human-robotic teaming has not been studied to the best of our knowledge. Therefore, this paper's studies about using different systems collaborating to do an inspection using human-robotic teaming and develops algorithms collaboratively in an indoor setting are proposed and will be presented in the next following sections.

III. Proposed Heterogeneous System Architecture

The proposed heterogeneous system architecture has 3 systems that works collaboratively in order to perform powerline inspection using human-robotic teaming. The illustration of the collaborative human-robotic teaming can be seen in Figure 1.And the individual systems that exists in this illustration are defined in detail as follows:

- An autonomous unmanned ground vehicle system that will take tasks from the human control system to drive through the path determined.
- An autonomous unmanned aerial vehicle system that conducts the powerline search and inspection within a specified range.
- A control system operated by the human that takes cares of the Autonomous car and drone functionality.

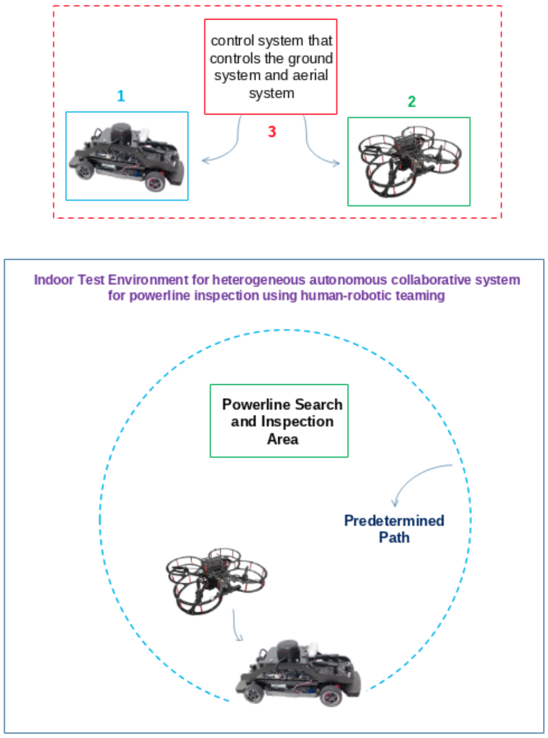

Fig. 1. collaborative human-robotic teaming.

This section of the paper talks about each system individually and the algorithms that are implemented in each systems.

A. An autonomous unmanned ground vehicle system that will take tasks from the human control system to drive through the path determined:

In this system, QCar was used as an Autonomous ground vehicle system trained to attain a self-driving capability and navigate a predefined path autonomously. To achieve this capability, a reinforcement learning algorithm called Q-learning has been used to train the model by providing a state and action scenario using exploiting and exploring techniques by updating the table and assigning the reward based on the agent's actions. Instead of training the model in a simulator for QCar to attain self-driving capability, this model uses in a real-world controlled environment in an indoor lab setting. Figure 2 illustrates the training environment for the QCar in an indoor lab environment.

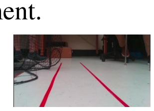

Fig. 2. Training environment for the QCar.

Once the model is trained enough to recognize the boundaries of the path and to determine an optimal steering angle in order for the QCar to remain centered in the path. The model is deployed on to the QCar with an option of having to switch back to manual mode if necessary from the controlled system.Which allows the QCar to make minimum errors and the human is always in the loop. While the model is deployed and is started driving the QCar sends the video input from the Intel RealSense camera through the CNN in order to receive an action, in this case a new steering angle. A reward will then be determined based on how close the new angle is to the actual angle of the path. The actual angle of the path will be determined by taking the video input and processing it in a way that determines the boundaries of the path based on their contrast to the surrounding environment and calculating the steering angle that they are pointing. If the reward is high enough, the video frames pertaining to the suggested angle is added to the dataset used to train the model. The steering angle of the QCar is then updated with the new steering angle with the highest reward. The flow Chart for this entire process is demonstrated in figure 3 which can be seen below.

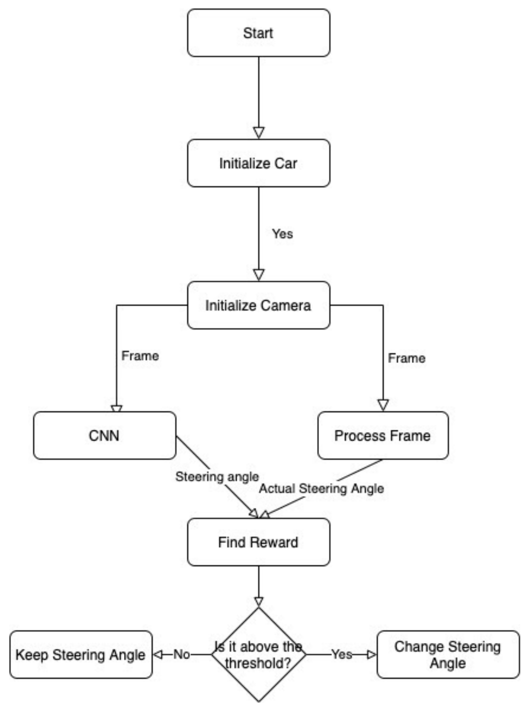

Fig. 3. Flowchart for QCar self driving mechanism.

B. An autonomous unmanned aerial vehicle system that conducts the powerline search and inspection within a specified range:

This is the third system that is entirely operated using different environment where the unmanned aerial vehicle system that conducts the powerline search and inspection with in a specified range in an indoor environment. The algorithm that was administered in this system is used in order to perform the powerline search and conduct inspection using QDrone. This flow chart of how the algorithm works is described below and is presented in the Figure 4.

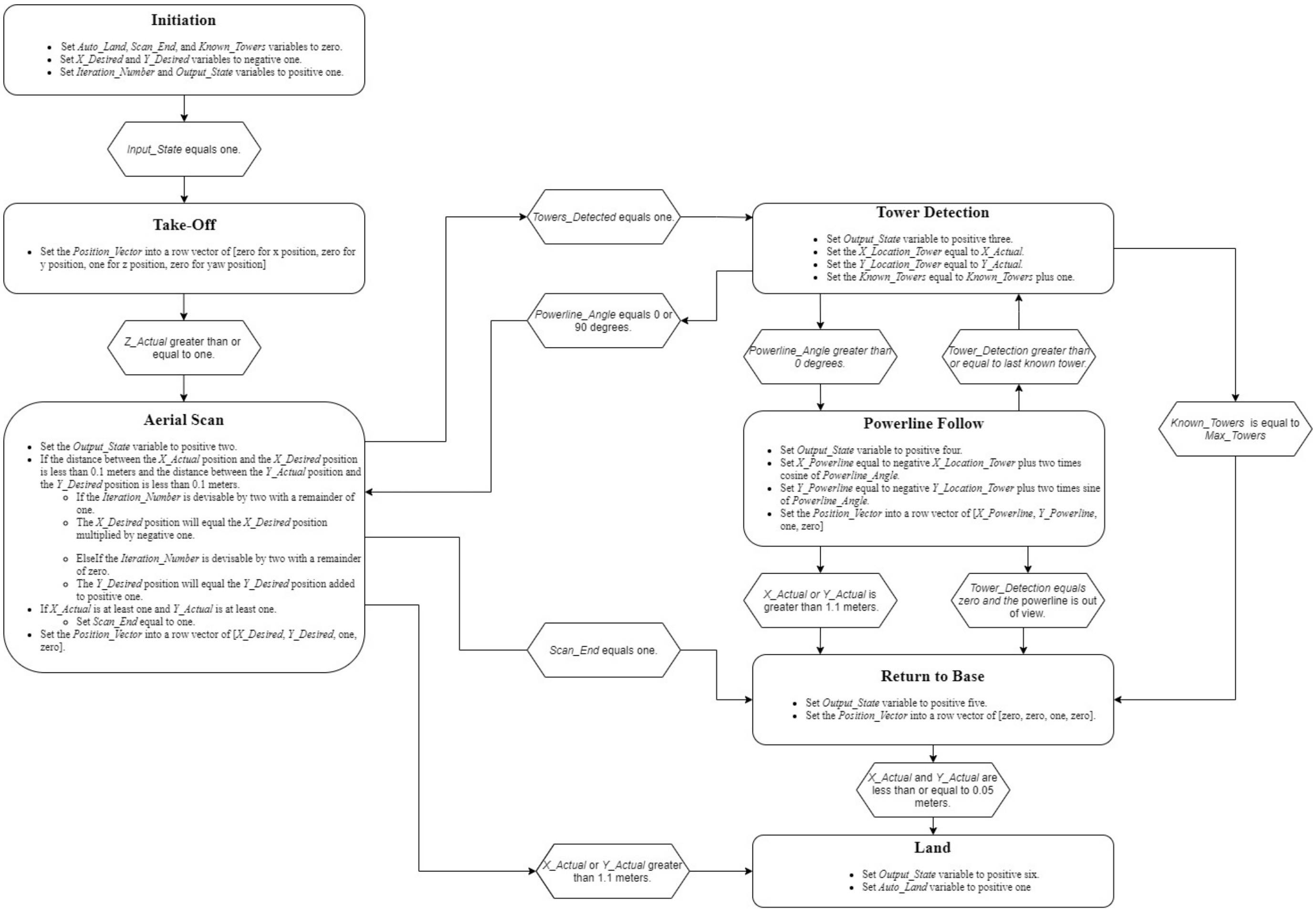

Fig. 4. Flowchart for QDrone autonomous vehicle.

In this algorithm, there are six different states where a different set of actions are assigned in each state for the drone to do a specific task. In this section, each of these states is described in how powerline search and inspection is carried out. The first state is the Initiation state, in which variables are initialized inside the state flow machine. The variables set in this state are Auto-Land, Scan-End, and the Know-Towers are set to Zero. Then the desired variables X-Desired and Y-Desired are set to a negative one. Finally, initializing setting the initial and final variables set in the Initiation state is Iteration-Number and Output-state to a positive one. Initialization is crucial to the state flow machine so the drone can make the correct assumptions before a flight. After the variables are initialized, the state flow machine transitions to state 2, Take-Off. In Take-Off, the QDrone increases in altitude to a height of 1 meter. When the altitude of the drone is at least 1 meter, the state flow machine transitions to state 3, Aerial Scan, once the QDrone enters the Aerial Scan after initiation and takes off states once the drone is given a command on the specific area from the control system then In Aerial Scan, the QDrone flies a gridded pattern based on an algorithm in the code to analyze the entire area searching for utility poles. If a tower is detected, the QDrone then proceeds to fly over the top of the found tower, and the state flow machine is transitioned to state 4, Tower Detection. If no utility poles are located, then the state flow machine transitions to state 6, Return to Base. If by some chance the QDrone's location exceeds 1.1 meters away from its initial position in any direction besides vertically, the state flow machine transitions to state 7, Land, and the QDrone is immediately landed. Once the state flow machine has transitioned to state 4, Tower Detection, the location of the found tower is noted, and the number of known towers is recorded if the camera loses sight of the powerline, the state flow machine transitions back to state 3, Aerial Scan. If the number of towers found is equal to the number of towers the user input before the flight, the state flow machine transitions to state 6, Return to Base. If the powerline angle is greater than 0 degrees, the state flow machine transitions to state 5, powerline Follow. In powerline Follow, the following utility pole is found by flying along the powerline, which is done through calculations based on the powerline angle and a standardized distance between utility poles. Suppose the distance from the last known tower exceeds 2 meters, then the state flow machines transition back to state 4, Tower Detection. If there are no utility poles or powerlines in the camera, feed the state flow machine transitions to state 6, Return to Base. If the position of the QDrone exceeds 1.1 meters away from its initial position in any direction besides vertically, the state flow machine transitions to state 6, Return to Base. In Return to Base, the Qdrone returns to its initial position. If the QDrone is within 0.05 meters of its initial position, the state flow machine transitions to state 7, Land. In Land, an auto land is initiated, and the QDrone lands safely. This is how the algorithm works for the third system.

C. Control system operated by the human that takes cares of the Autonomous car and drone functionality:

This control system will take care of sending instructions to the QCar and Qdrone about the predefined path, and then perform powerline inspection.All these activities are performed under the supervision of the human controller where the human has the control all the time in the tasks that are carried out by these two autonomous systems and feedback signals are send back to this control system.This kind of communication system will helps human robotic relationship between different heterogeneous system become more reliable and trustworthy.

IV. Testing the Proposed Architecture in an Indoor Environment

This section of the paper discusses about on how the proposed heterogeneous systems works in an indoor environment.The illustration of the proposed system is demonstrated in the following pictures below in Figure 5.By combining all the systems that were mentioned in the above sections the novel system architecture is tested in a controlled indoor lab environment and successfully established the powerline inspection.

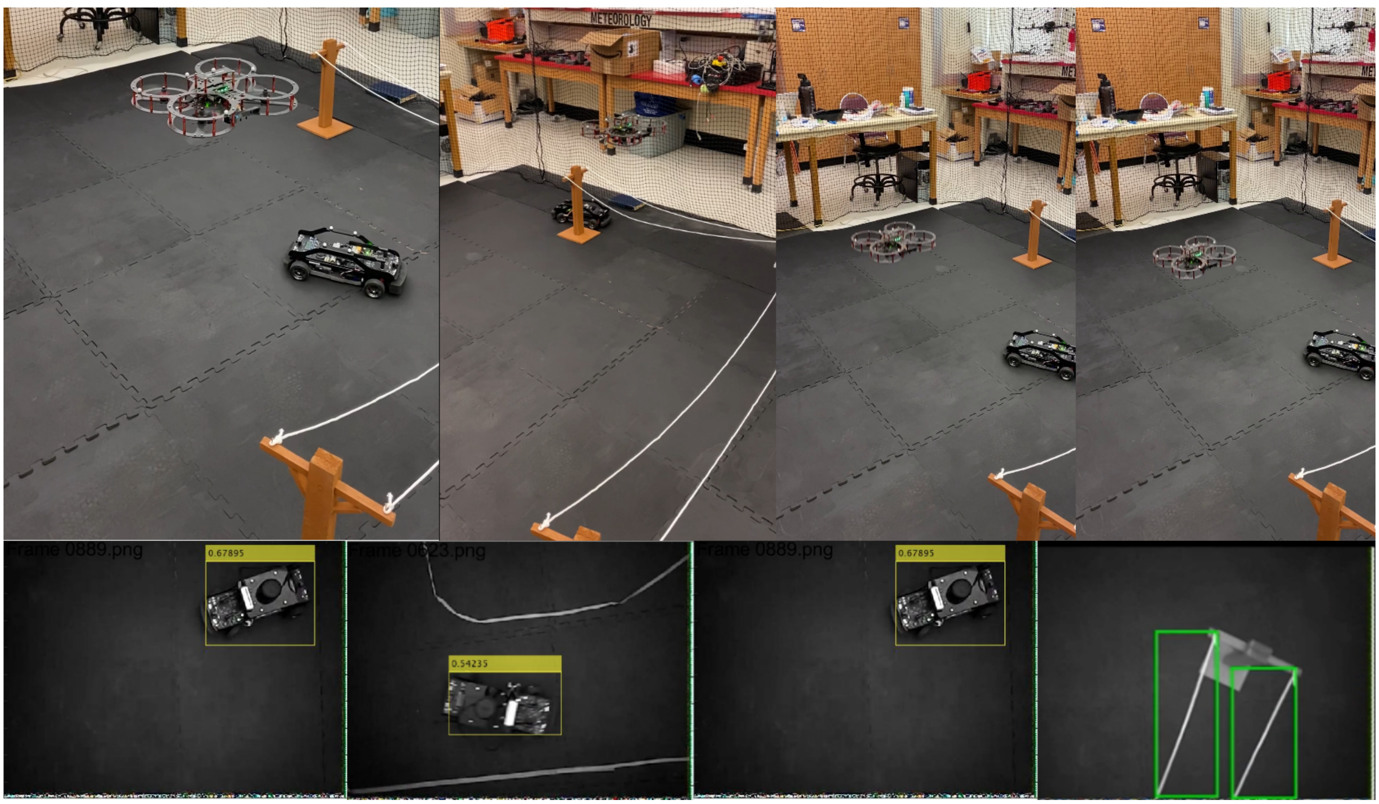

Fig. 5. Test Environment of the Proposed System.

V. Conclusion and Future Work

In this paper the use of this novel human-robotic teaming approach for powerline inspection architecture not only improves the efficiency but also eliminates the drawbacks associated with the UAV inspection such as battery life, amount of area that can be inspected and mainly gives control to the humans for using autonomous systems with in the populous areas and makes the inspections fast and reliable. Since this system is designed and tested in the indoor environment.For the future work researchers are planning to implement the same architecture in the outdoor environment as well.That will be the future work associated with the paper.

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