STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Autonomous Drones Controls and Indoor Navigation

DOE-FIU SCIENCE & TECHNOLOGY
WORKFORCE DEVELOPMENT PROGRAM

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ABSTRACT

Big data is ushering in an era of machine learning models and advanced analytics used to solve the world's problems. Collecting that data accurately and efficiently now becomes the bottleneck to data-driven models and simulations. New systems are being designed with data pipelines in mind and connectivity a given, but updating and transitioning legacy systems has become a roadblock to implementing big data analytics in industries that would stand to benefit. A novel approach for harvesting data from existing non-connected systems and infrastructure has been developed at Idaho National Laboratories (INL) that will remove the reliance on humans to manually transcribe data from outdated meters, dials, and displays. By using consumer off-the-shelf (COTS) quadcopters that come with streaming video capability, machine vision models and control system algorithms have been developed to navigate these quadcopters indoors using only visual references. GPS cannot be relied upon when in large facilities, and advanced sensors such as ultrasonics and LiDAR become cost prohibitive due to development and hardware costs. Instead, using a monocular video feed streamed over Wi-Fi, the drone can relay images of its surroundings back to a server where machine vision models can determine its relative location to obstacles within view, then using a control API, send commands back to the drone to navigate within its surroundings to achieve tasks such as routine security inspections, gauge and meter readings, and collection of qualitative data for structural assessments.

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1. INTRODUCTION

As the world continues to search for new sources of clean energy to combat the climate effects of dependence on fossil fuels, it is important to also consider means for sources of energy to become more efficient, safer, and more cost effective. Nuclear technology has always been a steady source of clean energy. There are in fact several success stories in the nuclear energy industry such as France, which derives about 75% of its electricity from nuclear power plants around the country (World Nuclear Association, 2020). Unfortunately, due to the high construction and operating cost of nuclear power plants coupled with low fossil fuel prices, the United States has not embraced nuclear power in the past decades as France has (World Nuclear Association, 2020). In a market that has moved towards deregulating the energy supplies, it is increasingly more difficult to fund the construction of new nuclear power plants; and with tight regulations on existing plants – some of which were built more than 50 years ago – it is not always feasible to retrofit them with new technology that will allow the plants to operate more efficiently.

2. EXECUTIVE SUMMARY

This research has been supported by the DOE-FIU Science & Technology Workforce Development Initiative, an innovative program developed by the U.S. Department of Energy's Environmental Management (DOE-EM) Office and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2020, a DOE Fellow intern, Michael Thompson, spent 10 weeks doing a summer internship at Idaho National Laboratories in Idaho Falls, ID under the supervision and guidance of Senior Research Scientist, Ahmad Al Rashdan. The intern's project was initiated on June 20, 2020 and continued through November 20, 2020 with the objective of developing programmatic control algorithms to navigate an autonomous drone indoors without the assistance of GPS and using only a monocular video feed.

3. RESEARCH DESCRIPTION

There is an ever-increasing demand for technology to make nuclear power plants more cost efficient. One main advantage of nuclear power is the relatively cheap costs of fuel compared to other forms of energy. Currently, fuel from a nuclear plant accounts for just 14% of operating costs, while fuel accounts for nearly 78% in coal-fired plants and 87% in gas-fired plants (World Nuclear Association, 2020). The majority of generating costs of nuclear power comes from the increased levels of security and safety that must always be maintained inside the plant compared to a traditional fossil fuel plant. Many of these costs are a result of the high number of highly qualified staff, which evolved over decades of operations. The nuclear power industry has historically resorted to adding more staff to address any new safety concerns, a model that impacted the industry’s economic sustainability. In several cases, new technology would be able to replace or augment some of the staff functions and mitigate these costs, however, due to regulations in a nuclear plant, it is not always cost-effective to update legacy technologies. Many plants operating in the U.S. today, for example, were built before the proliferation of digital technology and are dependent on analog gauges to monitor processes throughout the plant. Without the ability to update the infrastructure, manual readings of gauges across multiple fields and rooms must be made on a routine basis (referred to as operator rounds), multiple times a day in many cases. In addition, physical inspections of equipment must still be done as new sensor systems cannot be installed without excessive design modifications and regulation reviews. Therefore, a solution that does not require modification of existing systems, but will allow for the automation of routine tasks such as operator rounds and inspections, is needed to reduce operational costs of legacy plants and to provide a road map for future plants to increase automation.

Scientists throughout the U.S. Department of Energy (DOE) and throughout the world are working on ways to automate the tasks of humans in power plants through various means. Senior Research and Development Scientist at Idaho National Laboratories (INL), Dr. Ahmad Al Rashdan, has proposed a unique solution that involves flying self-navigating drones indoors to perform routine inspections of rooms and hallways, as well as instrumentation such as gauges and switch statuses. The proposed idea would utilize any commercially available drone with an adequate camera and control application programming interface (API). A video stream from the drone’s camera may then be processed locally on the drone or sent over a wireless connection to a remote computer where visual in the drone’s environment can be extracted and run through algorithms that will allow the drone to self-localize and plot a trajectory in the environment while avoiding collisions with walls and other objects. Similar to the way humans may navigate using landmarks, the drone would be able to reference the size and shape of objects within its field of view to determine its distance from the object and heading with respect to the object.

4. RESULTS AND ANALYSIS

In order to facilitate a self-navigating drone, several things needed to be developed and researched. First, due to the restrictions from the COVID-19 pandemic, it was not possible to fly a drone in person to perform tests, therefore a real-physics simulation environment was utilized where an exact replica of the drone, its firmware, and the environment it would fly in, could be modeled. Second, several algorithms needed to be written or sourced to identify specific visual features from a video frame. Third, an algorithm would need to be created to calculate the drone's position and heading with reference to the visual feature extracted. Next, a mathematical controller needed to be created to accept the error between the drone's current position and an intended waypoint; and finally, software was needed to integrate all of the previous parts together into a singular program that could receive a video stream from the drone and then relay commands back to the drone to control its flight in near real-time.

Summer interns in the previous year were able to complete a rudimentary proof of concept that served as a guide for where the work should start; however, it was decided that for this attempt, to take the project further whereby the development of algorithms and code would start from scratch.

5. CONCLUSION

Unfortunately, due to the export controlled nature of the project, not much may be discussed outside of very high-level extrapolations. However, it can be said that the project was an overall success. A computer vision module (CVM) was developed that relied on a custom machine learning model developed to rapidly find a specific visual feature in the drone's field of view. A software library was then used to extract higher fidelity markers from the visual feature which were then processed by a proprietary algorithm developed during this internship, which accurately calculated the position and heading of the drone. From there, autopilot software continuously processed frames from the camera feed, calculated the position of the drone down to less than 1 centimeter, and gave instructions back to the drone on what angle to tilt thereby flying it in a given direction and speed. The author was involved in all aspects of the technology development and was able to successfully model the behavior of the drone's response to various inputs allowing for a transfer function to be created from which controls could be tuned.

By the end of the project the drone was able to identify a visual feature no larger than 20cm across from over 6 meters away and then fly to any given location with reference to the waypoint as long as the feature remained in view of the drone's camera. Simple tests were initially setup to fly the drone in an open space with one visual feature (in the virtual physics environment). Once these were passed, a more realistic scenario was created where the drone would fly down a hallway in a U-shape. On the walls of the hallway were specific visual features to guide the drone and at the end was a landing pad where the drone would land at the end of its run. The algorithms and software proved to have little to no trouble guiding the drone in real-time to its destination without any collisions with walls or missing the landing pad. The drone was able to cover approximately 18 meters of ground, make a 90-degree turn twice, and position itself precisely over a landing pad, and land with an accuracy of less than 5cm, all under 45 seconds.

Expected future work for this project will include object detection and avoidance, especially of moving objects such as workers that may be in the hallways the drone is traveling down. During this project, the novelty of the new developments by the team were grounds for the project team to file for a new patent application with INL. The author is listed as one of the inventors, and one of the others on the patent is DOE Fellow and FIU student, Roger Boza.

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