Machine Learning Applications for NASA Droplet Image Analysis Report

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Abstract

Our project tackles the problem of analyzing images of fuel cell droplets with various machine learning techniques for purpose of image recognition. The goal is to determine the correct radius as a function of time of a moving combusting droplet, taking into account obscuration of the image due to sooting, and loss of resolution due to diffraction. Our final product is aimed to assist NASA research into efficient fuels, for the purpose of ground and space travel. We tackled the problem with two similarly related, but distinct algorithms, one implemented in Matlab and the other in C++. The programs both implement the Hough Circle Transformation in seeking and measuring the objects size and diameter, but how each program executes and tackles different scenarios differs.

I. INTRODUCTION

The NASA Flame Extinguishment Experiment - 2 (FLEX-2) is the second experiment to fly on the International Space Station (ISS). The experiment analyzes small droplets of fuel to study the special spherical characteristics of burning fuel droplets in space.

The FLEX-2 experiment studies how quickly fuel burns, the conditions required for soot to form, and how mixtures of such fuels evaporate before burning. The aim of the experiment is to understand these processes, which could lead to the production of a safer spacecraft as well as increased fuel efficiency for engines using liquid fuel on Earth.

However, the number of fuel droplet samples to be analyzed reach well into the thousands, and are currently analyzed by hand. Analyzing consists of measuring the rate at which the fuel combusts, as a function of time, for various fuels and fuel mixtures.

First, a video of the combustion process is taken aboard the ISS, in the Multi-User Droplet Combustion Apparatus (Figure 1). Videos are then converted into TIFF images sequences, which can contain over 1000 frames. Since the fuel droplets are combusted in zero-gravity environments, the shape of the droplets assumes a spherical shape during their lifetime after the igniters light it. Each frame must be individually analyzed, by hand, by measuring the radius of the burning droplet. This is both a difficult and time consuming process—the estimated timeline for this portion of the analysis hovers somewhere around 4-5 years.

However, if the process were to be automated, say, by building a machine that could analyze the droplets, frame by frame, then the research timeline could be significantly accelerated, by a factor of years. Machine learning applications through image analysis offers the most promising solution. Our project focuses in on this problem, and attempts to alleviate the time cost by building such a software that can perform such an automated function.

II. METHODS

Within the scope of our project, there were several roadblocks that had to be overcome. First, there was the issue of what language to implement the machine in. While there was an old half-finished prototype of the machine we were trying to build, available to us to Matlab, the code was near unusable, and had to be rewritten from scratch.

However, Matlab had its own speed limitations as well. Since Matlab is a script language, it uses JIT compiler to translate the script into machine code. However, the other potential solution would be to implement our machine in C++. C++ is a compiled language, does not require an interpreter, and deals directly with the memory addresses. While the former option would be faster to implement, the latter option would offer great performance improvement, time-wise.

It was eventually decided that the best route would be to divvy up the team into two factions: one would focus on implementing the code in Matlab, as a means to investigating which methods and algorithms would be a good route to follow, and the other would focus on the main implementation of the machine in C++, which may trail the Matlab prototype in algorithmic evolution, but take lead in performance.

The second roadblock was building testing the code on the data sets available to us. The biggest issue that we had to resolve was training the machines to recognize droplets in dubious situations when the droplet was difficult to spot under human examination. Examples of such situations include when then there was much ash swirling around the droplet creating circular patterns that would confuse the machine, when there was so much soot that the resulting image was far too blurry to be immediately decipherable, or when dealing with Ultra-Violet image sequences of the droplet, where the resulting frames would be near pitch black, with only faint hazes available for identifying the droplet's location and path.

III. RESULTS AND IMPACTS

The results yielded offered significant improvements to the research efforts, in reducing the time length of the analysis. Both machines were ran on 5 sets of simulated image sequences. The simulated images sequences increased in noise presence of the images, each sequence presenting a more difficult situation than the last in identifying correctly the location and radius of the droplet. Both machines also yield mean squared errors of less that 1.5 for all simulated image sets, which was very promising. For the C++ run, the code took roughly 30 seconds to process a single image sequence, of typical length.

This could reduce the projected computation time down to the span of weeks, if the machines were to run on all data sets taken during the experiment. If the software machines that were built were to be further improved on such that they could tolerate even more outlier cases of droplet identification, and then utilized in the final experimental analysis for FLEX-2, the experiement's research efforts could be capitalized on sooner. Since the FLEX-2 experiment has such a broad area of impact, the possibilities of knowing sooner, what fuels would be better suited for spacecraft or earth based engines are immense. One possible application of the results of the experiment would be that it could improve the methods by which satellites are launched into space, or how such spacecraft are repaired and maintained while in orbit. In this scope, our project has the potential to acerbate such possibilities into the near future.

Multi-User Droplet Combustion Apparatus

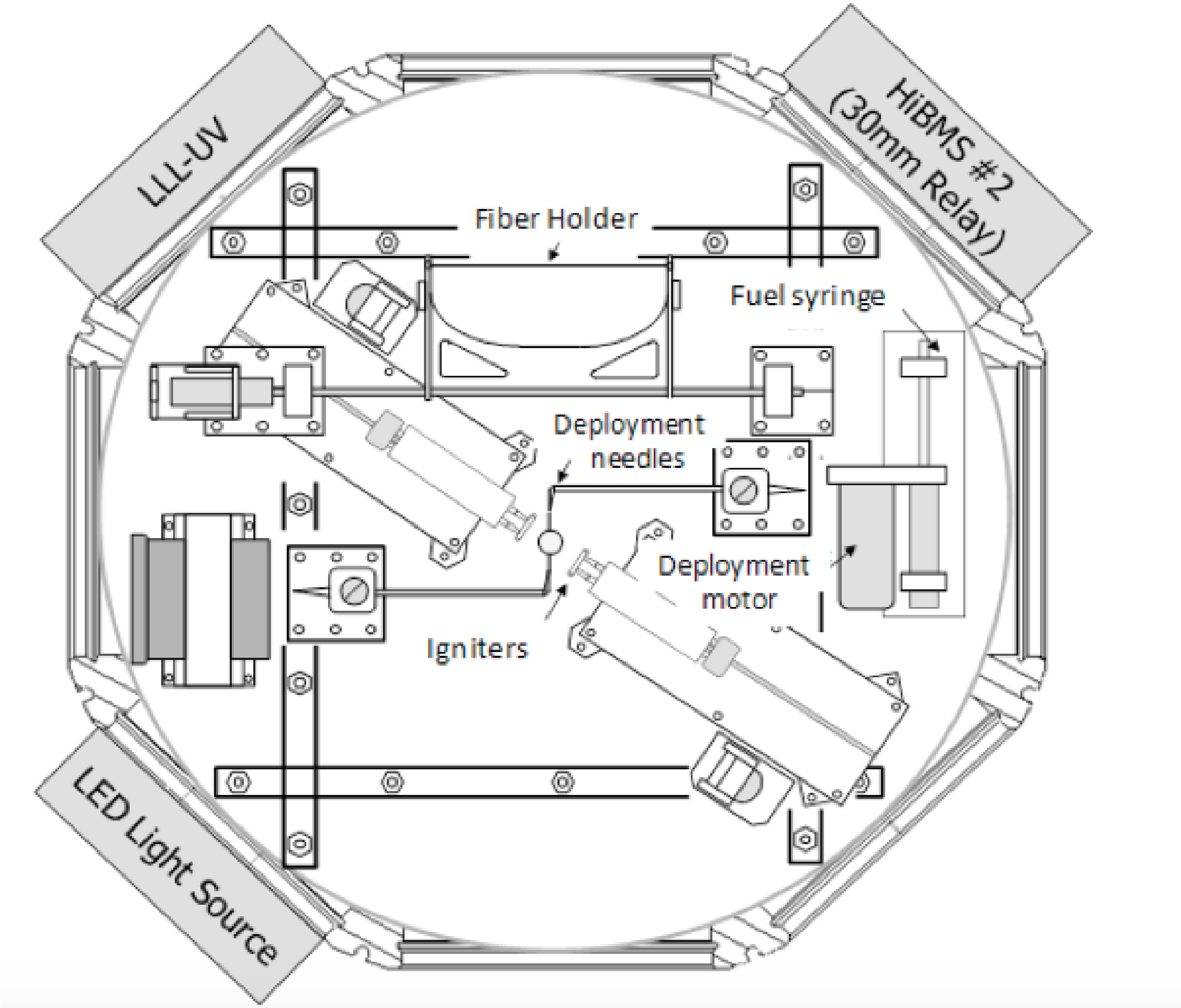

FIG. 1. Above is a schematic of the Multi-User Droplet Combustion Apparatus used in the experiments. The cameras are probably about 30 cm away from the burning droplets. There are several pure fuels that have been investigated, including: methanol, ethanol, n-heptane, n-octane, n-decane. Fuel mixtures (n-heptane/n-hexadecane and n-propanol/glycerol) have also been burned. These fuels exhibit various levels of sooting, burning rates, and extinction behaviors and also different liquid transport behaviors (for the mixtures).