Mission Space Lab Phase 4 Report

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Chosen theme: Life on Earth
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Introduction

Embarking on a journey of scientific exploration, our team initiated an AstroPi mission two years ago. This ambitious project aimed to determine the orbital speed of the International Space Station (ISS), utilizing the unique perspective offered by the station's orbit to analyze and investigate the diverse cloud formations enveloping our Earth.

This initial endeavor provided valuable insights and forged the path for further atmospheric investigation. This year, building upon this strong foundation, we have launched our next AstroPi mission with a refined focus. This mission aims to delve deeper into the intricacies of cloud formations, specifically focusing on understanding atmospheric gravity waves and their associated patterns, as observed from the vantage point of the ISS. By capturing and analyzing these unique images, we hope to expand our understanding of cloud patterns and the intriguing atmospheric gravity waves that are often associated with them.

Our focus on cloud pattern analysis and the detection of atmospheric gravity waves aligns with global efforts to improve our understanding of weather patterns and climate change, as well as the broader goal of protecting our planet for future generations.

In order to execute our experiments, we engineered Python scripts, effectively facilitating the data and image collection necessary to validate our hypothesis. Utilizing this code, we conducted a data acquisition session on May 2, 2023, spanning from 10:14:07 to 13:09:06.

Cloud Pattern Analysis

Cloud patterns provide critical insights into the dynamic nature of Earth's atmosphere and the complex interactions between air masses. These patterns are manifestations of various atmospheric processes such as convection, advection, and the effects of local topography. For instance, wave-like patterns in cloud formations are commonly observed under certain atmospheric conditions, particularly within stable atmospheric layers.

Stable atmospheric layers are characterized by minimal temperature change or even temperature increase with altitude. Any disturbances within these layers can trigger wave-like movements akin to the ripple effect observed on a pond's surface. If the layer is humid enough, cloud formation occurs at the wave crest where air flows upwards. Conversely, the downward-flowing air at the crest leads to cloud evaporation. This process results in a distinct wave pattern in the cloud formations.

Atmospheric Gravity Waves and Lenticular Clouds

Atmospheric gravity waves are a fascinating phenomenon associated with wave-like cloud patterns. They form when buoyancy acts as a restoring force on a displaced air parcel, causing it to oscillate vertically. The resultant pattern forms a "wave cloud," which is often an indicator of atmospheric stability and turbulence, key factors in weather forecasting and climate modeling.

In a specific scenario where air flows over a mountain or a hill, these atmospheric gravity waves give rise to lenticular clouds. Lenticular clouds are identifiable by their smooth, symmetric, lens-shaped appearance, often resembling a flying saucer. These clouds are stationary, with their position determined by the terrain that initially disrupted the airflow.

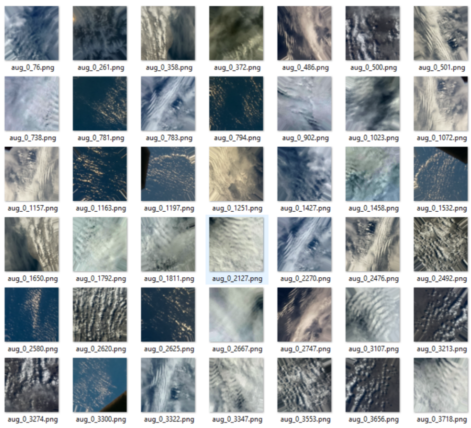
Methodology

We put the Astro-Pi's camera to good use! Our program made the camera snap a new picture every 10 seconds. But that's not all - it also recorded measurements from the Astro-Pi's sensors every single second. To keep track of all this, each piece of data was stamped with the exact time it was collected and then neatly written into a log file.

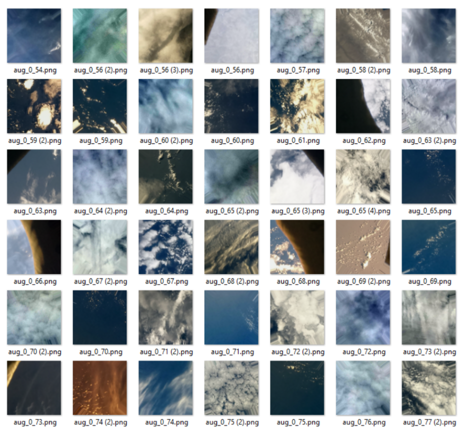
Altogether, our Astro-Pi mission collected a whopping 1,389 images and a grand total of 103,870 data samples from the onboard sensors. Out of all these photos, we found that 52.8% were just right for our cloud pattern analysis and image classification tests. Once we had collected all the data up in space, we brought it back down to Earth (digitally speaking!) to do all our number-crunching and analyses. It's been an exciting journey, and we can't wait to share our findings! For a deeper dive into our project, including all the nitty-gritty details and the code we used, feel free to check out our well-documented GitHub repository[1]. We've shared everything there!

Our methodology centered around the utilization of images previously captured (from 2021 and 2022) from the ISS. We developed a comprehensive dataset consisting of cropped images, each 240x240 pixels,

Atmospheric waves



Non atmospheric waves



[1] https://github.com/CNME-LionTech/AstroPi-2023

derived from these original images.

To significantly increase our data set and ensure the robustness of our subsequent analysis, we used TensorFlow's Keras, a powerful open-source tool for data augmentation. This process helped us create a more extensive collection of images both with and without atmospheric waves. Data augmentation techniques such as rotation, zooming, and horizontal flipping were employed to introduce variability and improve the model's ability to generalize from the training data.

Model Training and Classification

Post data augmentation, we implemented a classifier using a convolutional neural network (CNN), an architecture renowned for its efficacy in image classification tasks. CNNs can effectively learn the hierarchical pattern in data by applying the right filters, trained using backpropagation, ultimately achieving the task of image recognition.

The model was trained on our large set of images, enabling it to distinguish images with atmospheric wave patterns from those without. The model was then put to the test on a new set of images received from the ISS a month ago.

```
Found 28763 images belonging to 2 classes.
Found 256 images belonging to 2 classes.
Epoch 1/10
899/899 [==============================] - 1130s 1s/step - loss: 0.0473 - accuracy: 0.9948 - val_loss: 0.4070 - val_accuracy: 0.9258
Epoch 2/10
899/899 [==============================] - 1566s 2s/step - loss: 0.0280 - accuracy: 0.9960 - val_loss: 0.3376 - val_accuracy: 0.9258
Epoch 3/10
899/899 [==============================] - 1468s 2s/step - loss: 0.0267 - accuracy: 0.9960 - val_loss: 0.3895 - val_accuracy: 0.9258
Epoch 4/10
899/899 [==============================] - 1425s 2s/step - loss: 0.0306 - accuracy: 0.9960 - val_loss: 0.3654 - val_accuracy: 0.9258
Epoch 5/10
899/899 [==============================] - 1258s 1s/step - loss: 0.0334 - accuracy: 0.9950 - val_loss: 0.3651 - val_accuracy: 0.9258
Epoch 6/10
899/899 [==============================] - 1624s 2s/step - loss: 0.0261 - accuracy: 0.9960 - val_loss: 0.4016 - val_accuracy: 0.9258
Epoch 7/10
899/899 [==============================] - 1652s 2s/step - loss: 0.0269 - accuracy: 0.9960 - val_loss: 0.3616 - val_accuracy: 0.9258
Epoch 8/10
899/899 [==============================] - 1463s 2s/step - loss: 0.0276 - accuracy: 0.9959 - val_loss: 0.4577 - val_accuracy: 0.9258
Epoch 9/10
899/899 [==============================] - 1277s 1s/step - loss: 0.0274 - accuracy: 0.9960 - val_loss: 0.3793 - val_accuracy: 0.9258
Epoch 10/10
899/899 [==============================] - 1379s 2s/step - loss: 0.0266 - accuracy: 0.9960 - val_loss: 0.4468 - val_accuracy: 0.9258
```

Figure 1. Visualizing the journey of model training: each epoch brings us one step closer to accurate atmospheric gravity wave detection.

Having identified the images containing atmospheric gravity waves, the final step of our mission involved spectral analysis. This scientific method uses the principles of wave physics to extract valuable information about the frequency, amplitude, and overall characteristics of the gravity waves present in the images.

Spectral Analysis: The Final Step

Our methodology for spectral analysis of atmospheric waves consists of the following steps:

1. Image Preprocessing: After isolating wave patterns, we align them horizontally through image rotation using the Hough Transform. This ensures uniform orientation for accurate analysis.

2. Spectral Analysis: Applying a 2D Fast Fourier Transform (FFT) to the horizontally aligned wave pattern, we transform the image from the spatial domain to the frequency domain. This reveals frequency components that signify the wave pattern's periodicity.

3. Calculating Wave Period: From the frequency components obtained through spectral analysis, we determine the wave period, representing the time for one complete cycle of the wave pattern. The wave period is calculated as the inverse of the dominant frequency component.

By following this comprehensive procedure, which includes image preprocessing, spectral analysis, and wave period calculation, we gain a deeper understanding of atmospheric wave patterns. This contributes to our knowledge of atmospheric dynamics, unveiling the periodicity and characteristics of these fascinating phenomena.

Conclusion

In conclusion, our AstroPi mission focused on the analysis of cloud patterns and the detection of atmospheric gravity waves using images captured from the International Space Station (ISS). Through the utilization of advanced techniques and methodologies, we aimed to expand our understanding of atmospheric dynamics and contribute to the broader knowledge of weather patterns and climate change.

Our mission encompassed various stages, starting with data acquisition and image collection using Astro-Pi's camera and sensors. The collected dataset consisted of 1,389 images and over 103,870 data samples. After careful preprocessing and data augmentation, we trained a convolutional neural network (CNN) to classify images with and without atmospheric wave patterns.

The trained model proved effective in identifying atmospheric wave patterns in a new set of images received from the ISS. Moreover, we delved into spectral analysis to extract valuable information about the frequency and characteristics of the gravity waves present in the images. The calculated wave period provided insights into the cyclic behavior of the wave patterns.

Our project's detailed procedures, including image preprocessing, spectral analysis, and code implementation, are available on our GitHub repository. This comprehensive documentation serves as a valuable resource for those interested in replicating or further exploring our work.

By combining advanced imaging techniques, machine learning, and spectral analysis, we have made significant strides in understanding cloud patterns and atmospheric gravity waves. This research contributes to the broader scientific community's knowledge and aids in predicting weather patterns, studying climate change, and enhancing our understanding of Earth's atmospheric dynamics.