# Team Discount GPT: Large Binocular Telescope Misalignment Project Report Survey

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## ABSTRACT

The Large Binocular Telescope (LBT), situated in Southern Arizona, is a state-of-the-art observatory boasting two massive 8-meter mirrors that set it apart from its traditional single optic counterparts. However, the utilization of two primary optics leads to unique misalignment issues that may result in sections of blur on the captured images. The LBT team is currently grappling with pinpointing the origin of this misalignment, which could stem from optical, mechanical, or software-related causes due to the complex nature of the system. To address these challenges, the team has developed a custom IDL program dubbed "LBCFPIA," which performs geometric analysis of extrafocal pupils to determine focus and wavefront corrections via third-order spherical aberration.[1] Despite the effectiveness of this system, its time-consuming nature, requiring 20-40 minutes per iteration and multiple iterations that depends on specialized input for accuracy, necessitates an alternative approach. Our research proposes a Machine Learning model that can perform precise regression analysis utilizing image data and data from the Point Spread Function (PSF) subsystem to predict control parameters that can be used to correct misalignment issues, thus replacing the current LBCFPIA system.

## 1. WHAT HAS BEEN DONE?

One of the most important thing is understanding where our data comes from and what we are trying to solve. In that regard, reading about how the telescope works and what has already been accomplished regarding how LBCFPIA operates was the first step in our research into the topic. The paper Prime Focus Active Optics with the Large Binocular Telescope[1] details the development and implementation of the current optics system being used. The authors of the paper conducted a series of tests to evaluate the performance of the LBCFPIA. They found that the system improved the telescope's image quality and reduced the effects of atmospheric turbulence. Additionally, they demonstrated that the active optics system could be used to compensate for telescope misalignment and other mechanical issues.

Correctional data is sent from the LBCFPIA to the PSF subsystem. The point spread function describes the response of an imaging system to a point source, such as a star. In other words, it is the pattern that results when a point source is imaged by the telescope and the image is projected onto a detector. The PSF is a measure of the telescope's image quality, and its shape is affected by a number of factors, including the telescope's optical design, the atmospheric conditions, and the size and shape of the telescope's aperture.

In the paper, the authors discuss how the active optics system implemented on the Large Binocular Telescope helps to improve the PSF, which in turn enhances the quality of the telescope's images. By adjusting the positions of the primary and secondary mirrors in real-time to compensate for changes in the environment, the active optics system reduces the distortion of the incoming light and improves the PSF. This results in sharper, clearer images that allow astronomers to study astronomical objects in more detail. In our simulated data, we will know the ideal conditions for the PSF and this will be one of the core parameters that will be used to train our model.

When looking for applied solutions our problems, we found a paper on Image-Based Regression Using Boosting Method that was published in 2005. This paper explores general regression algorithms that is applicable to various computer vision problems.[2] The paper proposes an efficient training algorithm that avoids the computational bottleneck of greedy feature selection through an incremental approach. The findings were validated on the following problems: age estimation, pulmonary tumor detection, and endocardial wall localization.

Previous research work has explored image orientation estimation with convolutional networks.[3] This paper focuses on the problem of estimating and correcting the exact orientation of general images. The author proposes that a convolutional network can learn subtle features to predict the canonical orientation of images. In contrast to prior works that just distinguish between portrait and landscape orientation, the network regresses to figure the exact orientation angle. The approach overall is applicable for our purposes due to the nature of how it approaches representing the image.

Machine learning and Deep learning approaches have previously been applied to different regression problems. For our project, we plan to use Deep Learning to provide useful approximations of the regression values needed during the alignment process.

Lathuiliere et al.[4] provide an analysis of different hyperparameter selections and training strategies on the results of Machine Learning and Deep Learning applied to regression. They compare 'vanilla' deep regression models, which are networks where only the last softmax layer is replaced with a fully connected regression layer while the remainder of the architecture is unchanged, against state-of-the-art methods. All of the regression models are evaluated on the head pose estimation, facial landmark detection, and full-body pose estimation regression tasks .

Lathuiliere et al. examine choice of optimizer, loss function, batch size, use of batch normalization and layer normalization, dropout, and which layers of the model could be updated during the fine-tuning process. Similar to Lathuiliere et al., during the exploration phase of our project we expect to test multiple 'vanilla' model architectures and will apply the results from Lathuiliere et al. regarding different hyperparameter selections and training strategies to efficiently train potential models.

Qiu et al.[5] propose the use of an ensemble of 'Deep Belief Networks' with a novel result-combination method that uses support vector regression to combine the ensemble results. Due to the high precision required for our regression task, ensembles may provide the improved precision that is necessary for our task results as well as improved generalizability that may allow us to overcome issues with the limited dataset size. However, using an ensemble requires more time to execute given the same computing power versus a single model, but is still expected to be significantly faster than the current alignment process. Additionally, the method used to combine the results of the ensemble of regression models can have a significant impact on the final results, and may require some experimentation when applied to our specific use case.

For the modeling purpose of the project, Ameri et al.[6] paper suggests using an electromyography (EMG) control scheme with a regression convolutional neural network (CNN) as it outperforms support vector machine (SVM) based scheme in throughput during single and multiple degree-of-freedom motor tasks because it allows independent and simultaneous control of motions. Moreover, regression CNN performed better due to higher accuracy, especially with high EMG amplitudes. This will be a massive factor in case of adjusting the LBT mirrors.

## 2. LIMITATIONS AND CHALLENGES

The determination of model performance is a critical question in the exploration of various models. To be practically applicable, models must exhibit high precision, since even small deviations along a single axis may result in unsolved misalignment issues. Although the ideal model would perform within an acceptable error margin on a single iteration, it is not currently feasible within the scope of our present objectives

This concern is linked to a potential issue with the task at hand, as our dataset is presently limited in size to less than 1000 samples. The efficacy of deep learning applications is reliant on the quality of the training data. Thus, performing high-precision regression with a limited number of training samples may necessitate the inclusion of new training strategies or methods for improved generalization, such as the aforementioned ensembling, in order to generate valuable outcomes.

To address these challenges, we are currently investigating approaches to generate additional data and examining various models that can exhibit strong generalization with limited data. Furthermore, incorporating human intervention and labeling similar to the LBCF-PIA approach represents a viable strategy to address our concerns.

## REFERENCES


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## 3. CONTRIBUTIONS

Everyone so far has been contributing to both the process of this research project as well as to the current project report here. Both the proposal, discussion of how to proceed forward, as well as the 1 minute pitch was done as a collective group with no one left out.

We have also started to plan out regular meeting times once Spring Break ends in order to fulfill the objectives that we are each tasked with in order to complete this project. Once progress has been made, we all plan to attend the TA session to help us further along our progress.

Ryan Luu - Wrote the abstract, researched and wrote about source 1, and worked on the limitations and challenges section.

Bowman Brown - Worked on sources 4 and 5 and limitations and challenges section.

Alfianto Widodo - Worked on sources 2 and 3 and limitations and challenges section.

Mahmoudreza Dehghan - Worked on source 6 and helped research into extra papers that did not make it into the final project report (though were very relevant and helpful for us to know about).

Additionally, it is worth noting that all team members have participated actively in editing each other's sections and the overall report as a whole.