Miri: a portable and low-cost microscope using a smartphone and image enhancing algorithms

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**Abstract:**

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# Introduction

The visualization of micron and sub-micron objects is important to detect microorganisms being them pathogens (Rodrigues-Fernandez et al., 2020) or regular cells (Moen et al., 2019), materials characterization (Inkson, 2016), etc. To detect the small objects is usually employed a microscope. This object, was created by Zacharias Janssen in 1585, being the first reported visualization of cells (Ball, 1966). Since then, the microscope evolved, and until the present day, there are different types of microscopes, such as optical (Mertz, 2019), electron (Spurgeon et al., 2021), fluorescence (Ulrich et al., 2017), with ultraviolet surface excitation(Fereidouni et al., 2017) and polarized light (Oliviero & Punzi, 2022) given the wide fields and applications of it. Despite being the microscope an important instrument for several applications, the cost of one is usually high, restricting the access of them to a small number of groups. This restriction can be a problem since the usage of microscopy is very important for modern healthcare (Breslauer et al., 2009). This problem can be solved by producing low-cost microscopes.

Several attempts aiming the production of low-cost microscopes has been endeavored recently using image techniques, ball lens and cellphones (Breslauer et al., 2009; Switz et al., 2014; Kobori et al., 2016). However, even employing low-cost techniques, there are several difficulties in obtain reasonable image resolutions while taking microscopic images due aberrations caused by the objective (Zheng et al., 2013), finite aperture (Switz et al., 2014) and flat field distortions (Smith et al., 2011). These difficulties can be overcome by employing techniques to improve the final image quality, reduce the distortions while also maintaining the principles of cost-effective and scalable manufacturing (Cybulski et al., 2014).

Some of these technologies relies on the usage of smartphones (Lee et al., 2021), ball and cheap leans (Kobori et al., 2016), 3D printed technology (Skandarajah et al., 2014), electronics (Dong et al., 2014) and computational process for image improvement (Aidukas et al., 2019). The usage of smartphones in the microscopy can has as consequence the portability of them, however, the images alone can have low resolution, affecting the analysis of them (Lee et al., 2021). Ball lens can expressively reduce the production cost of a microscopy, but the final image is distorted in the corners (Switz et al., 2014). 3D printed technology brings low cost and production scalability since the final equipment is relatively easy to prototype and produce in large scale (Skandarajah et al., 2014). Employing electronics in a low-cost microscope production can increase the number of parts needed, and time needed to assembly the equipment, reducing the applicability of the microscope in field (Dong et al., 2014). Applying computational processes after image acquisition can be a solution to improve image quality, by applying image manipulation techniques and algorithms to achieve that goal (Aidukas et al., 2019).

One example and is the Fourier ptychographic. It employs several low resolution images illuminated from different light sources directions, consequently different numerical apertures (NA), to compose a single high resolution image (Zheng et al., 2021). Kong et al. (2009) used a method known as self-adaptive plateau histogram to enhance microscopy images. Basically, in this method, the computer analyze several histograms of distinct parts of the entire image and redistribute luminance values throughout the image. Zhao et al. (2020) developed a machine learning method to deblur images obtained from microscopes, obtaining a method that includes a simple operation, a short time to compute, good deblur results and wide application among microscopical systems.

Aiming at the development of an affordable and high quality image, the objective of this project is to build a low-cost microscope using a smartphone. The structure will be designed and manufactured using 3D printed technology to assure scalable production and low-cost development. The lens will be made using affordable x5, x10 and x15 magnification lens among a laser pen lens. Lastly, a smartphone application using Flutter framework and Python language as backend will be responsible to send the light source using smartphone lantern, capture the image and apply the algorithms to the image captured.

# Materials and Methods

## 3D printed structure

The 3D structure of the microscope developed here was based on the microscope built by Lee et al. (2021), with some modifications. They used a professional lens, silver mirrors and a professional sample spacer, objects that are expensive, limiting the manufacture scalability. The microscope developed in this study uses 3 lens obtained from a magnifier, having 5, 10 and 15x magnification and X, X, X focal length and also a lens obtained from a cheap laser pen with 4cm of focal length and Xx magnification. The mirrors were regular ones, and the sampler spacer were developed by the author using Fusion 360 software (Autodesk, 2023).

The initial structure were made in the Fusion 360 software (Autodesk, 2023) in order to fit the new lens, maintaining the magnification properties. The magnification lenses with 5 and 10x were placed as the objectives, being the first one the closer to the sample. The lens with 15x and the obtained from the cheap pen were placed as the eyepiece, being the last one, the closer to the smartphone frontal camera. The sample spacer were developed to adjust the distance between the sample and the objectives by slightly rotating a knob. As the operator rotates the knob, the sample distance from the objectives is adjusted by decimals of millimeters. The smartphone placement were modified to fit modern smartphones, both Apple and Android based gadgets. The structure was printed using a 3D printer Anycubic Kobra Go with black PLA filament. The screws used in the structure junction were also 3D printed using the same equipment and material beforementioned.

## Algorithm

The algorithm front-end were developed in Flutter framework and Dart programing language and the local back-end were developed in Python programing language. Using this approach, instead of using Java programming language allowed the algorithm to work in both operational systems Android and Apple.

First, the user inserts the cellphone in the space designed for it, below the microscope, then press the button “Prepare” in the screen. Then, the smartphone lantern will turn on, while the screen will display the image that the frontal camera is capturing. The user then modifies the distance between the sample and the objective by rotating the knob until the image is focused. Second, the user press “Capture” button in the screen and the image from the frontal camera is captured. Lastly, in the local backend, the improvement algorithm runs.

The improvement algorithm is composed of a Self-Adaptive Plateau Histogram and Wiener filter for deblurring process.

## Performance evaluation

The performance of the microscope was evaluated by collecting images of the authors blood and semen, plant structures (root and leaf), fungal spores and inserted in the microscope. All the objects were collected randomly and prepared for the evaluation by the respectively sample preparation. Later, the low and high resolution images obtained were compared to images from the internet to evaluate the resolution of the microscope developed.