Telescope Prime:
an open source, 3D printed, telescope development platform

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Building a usable telescope capable of imaging Solar System objects has long been a domain of either professional astronomers, telescope makers or experienced amateurs. Beginners in the field of astronomy had to either attempt assembling a complicated off-the-shelf equipment[1] or settle on modifying one of many educational kits such as the LTI telescope or the *Galileoscope*[2]. The former approach requires a sophisticated understanding of astrophotography and a considerable financial outlay, while the latter is severely limited by poor quality of optics, small magnification, no obvious way to attach imaging sensors and a lack of stable mount.

As 3D printing became popular over the last decade, a serious attempt can be now made to fully circumvent the abovementioned limitations. In this context we present *TelescopePrime*, a powerful, open-source, 3D printed, low-cost telescope platform for beginners. We built it with two design principles in mind – to be accessible (price-wise and skills-wise) while fitting well into our XXI century, increasingly digitally connected lives. The result is a large (27 cm x 27 cm x 115 cm), prime focus telescope with integrated digital camera and an onboard image processing/streaming computer.

Design

The design consists of four main components (see Figure 1):

- A large, 203 mm diameter, 1000 mm focal length, parabolic mirror
- A 8MP camera attached to a microcomputer (Raspberry Pi) with touchscreen display
- A set of 3D printed parts to hold the above two components
- An optical tube assembly and telescope mount constructed entirely with off-the-shelf, home-improvement store supplies.

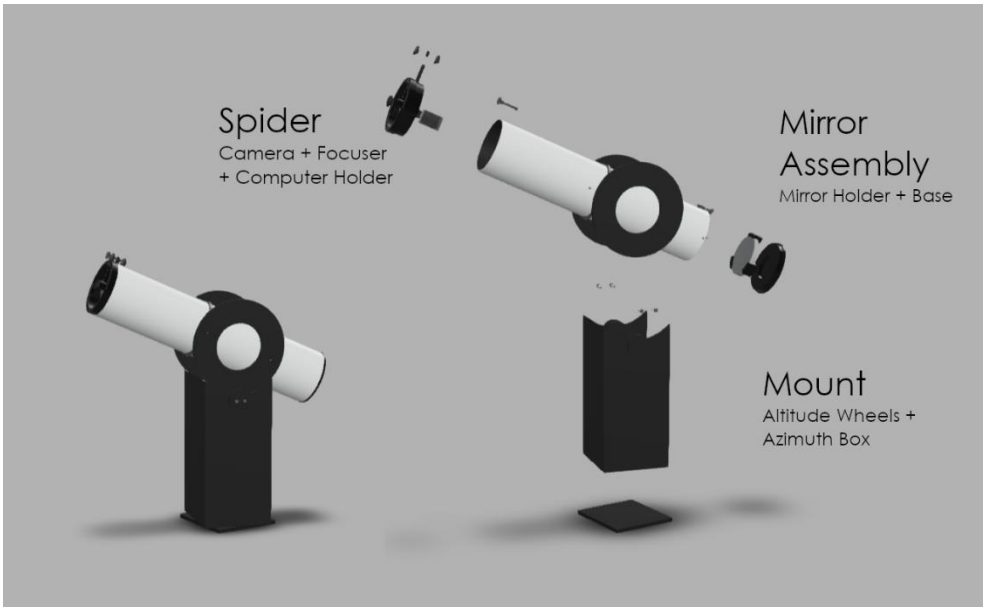

Figure 1: Rendering of TelescopePrime assembled (left) and exploded into three functional groups (right)

The large size of the telescope allows it to fit an array of large mirrors (sizes can vary from 150 mm to 250 mm diam., with 203 mm chosen as our default due to ease of access and good price to size ratio) – providing sufficient light gathering power to adequately illuminate small pixels (1.12 µm x 1.12 µm) of the chosen CMOS camera. Positioning of the camera in the prime focus of the telescope simplifies both the design (removing any secondary mirrors, lenses, and other optical elements) and day-to-day telescope operations, doing away with complex collimation procedure needed for most of the popular telescope designs.

The camera itself, a Raspberry Pi Camera v2, is small and lightweight enough to fit within the optical tube assembly, obstructing only a minimal part of the main mirror. At the same time, it integrates seamlessly with the Raspberry Pi microcomputer, allowing for the images captured by the telescope to be automatically broadcasted to the either the attached touchscreen display, via WiFi to other local network computers or even live on the Internet video sharing platforms. All that functionality is provided out-of-the-box with no extensive customization required, making the telescope a perfect platform for beginners keen on sharing their experiences of photographing the night sky for the first time. For advanced users, a Picamera python interface is also provided, making the telescope a highly customizable development platform for live astronomical image processing software. All the electronics can be

powered from a single 5V rechargeable battery (a typical *powerbank* for smartphones), from a standard USB laptop port or from mains (via a 5V charger). This makes the telescope easy to move and conduct observations from any location without the need for electrical outlets, large batteries, etc.

3D printed parts consist of the Spider, which holds the camera and our bespoke variable speed, high-precision focusing mechanism; Mirror Holder and Base assembly, allowing to aim the mirror and hold it firmly in all orientations; and Raspberry Pi holder, which provides a secure platform for the microcomputer and a touchscreen display. All parts can be printed on a standard 25 cm x 25 cm printer or ordered online using models provided on the project website: http://telescopeprime.pl

Finally, the telescope tube is made of a durable, 270 mm diameter cardboard shuttering tube, available in most home improvement stores. It provides mounting points for all 3D printed parts and can be itself attached to our custom designed, plywood alt-azimuth mount. Design for both the entire telescope and the alt-az mount can be also found on the project website, together with a proposed bill of materials.

All the abovementioned design choices make the telescope affordable (starting price from 235 EUR), easy to setup (assembly time < 8 hrs) and accessible to a complete beginner – providing a rich night-sky observing experience, which can be recorded and easily shared online.

Comparison to other 3d printed telescopes

It is worth noting that this has not been the first attempt at designing an open-source, 3D printable telescope. Two such attempts have been made before. A small (113 mm diameter) prime focus telescope, *PiKon*[3], is currently available as an open hardware project. It can be assembled using off the shelf equipment and a set of 3D printed parts. It suffers however from difficulties in focusing due to a low-precision of its cog-and-threaded-shaft focusing system and limits its imaging capabilities by obstructing significant part of the small mirror with a large and asymmetrical spider design. On the opposite side of the difficulty spectrum lies the *Ultrascope*[4], released by the Open Space Agency under the CERN Open Hardware License. It sports a robotic mount, which allows it to track even fast-moving asteroids. However, it proves to be immensely difficult to build for amateurs, requiring both a 3D printer and a laser cutter to manufacture its 60+ detailed parts. It is also

restricted for use with high-end smartphone cameras based on discontinued Windows Mobile OS and suffers from very low light collecting power due to its small 89 mm diameter mirror.

Platform and future plans

As the title of this abstract stipulates, this project should be understood as more than just a single telescope model that can be replicated multiple times. We wanted to create something that could evolve over time. That is why we decided to share our telescope with the world on our website by giving all the information needed for a DIY build. It is available for download under *Creative Commons Attribution, Non-Commercial, ShareAlike 4.0 International* licence. As such it can be also modified, upgraded and re-shared into a central repository, allowing the platform to evolve overt time both in terms of hardware and software. In time, we hope this project to reach a level of maturity when telescopes such as this one start replacing small, undriven, amateur off-the-shelf reflectors – providing easier access to the night sky to the beginners.

The long term goal of this project is to popularise and democratise astronomy by showing that one does not have to be a professional scientist or telescope constructor to create something big and interesting within the field. This project has been carried out so far primarily at school, albeit with support from a professional astronomer. We wanted to show that representatives of the younger generation, such as ourselves, have the possibilities and imagination to add new innovative input into the 400+ year history of the telescope.

Keywords: telescope, open source, 3D printed, astronomy

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