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The Telescope-in-a-box - A collapsible open-frame Dobsonian Telescope for Student Astronomy Projects

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The telescope-in-a-box is a small objective ultralight Dobsonian telescope concept that will be accompanied by telescope instrumentation lesson plans. This provides a rich set of opportunities for teaching astronomy, physics and engineering. Our first two prototypes demonstrate that it can be constructed at low cost, while many of the design decisions can lead to lesson plans in telescope instrumentation.

Keywords: Telescopes; Practical Astronomy; Astronomical Instrumentation.

1. Introduction

Telescopes are an essential teaching tool in astronomy[1], allowing students to connect in-class instruction to the real world through practical activities[2]. However, many commercial telescopes are large and bulky, or have limited light collecting area. In particular, many commercially available small telescopes are of the closed tube design, while truss or ultralight designs are commercially available only for larger aperture reflectors (generally 300mm objective diameter and larger) and tend to be more expensive.

These limitations place some constraints on the use of commercially available small telescopes in a classroom setting. The closed tube design of the more affordable models limit the in-class demonstration potential in that students do not necessarily get to see the inner workings of the telescope and tend to treat it as some sort of black box. At the same time, the higher cost of the truss or ultralight models mean that mass deployment of such models are far less feasible. To solve this problem, we have developed the telescope-in-a-box, a small objective ultralight Dobsonian telescope that is inexpensive, collapsible and lightweight with an open frame. This concept is based on the guiding principles of portability, cost and educational value.

To be portable, the telescope needs to be both lightweight and collapsible. The first prototype of the telescope-in-a-box proved that a collapsible design is practical, but its carrying weight will strongly depend on the choice of materials and engineering decisions that go into the final design. In contrast with commercial ultralight Dobsonians which are designed to be lightweight first, the telescope-in-a-box is designed to be compact first, with the intention that students may borrow a telescope set for independent observations. This is especially important because in Singapore, students generally travel by public transport and that makes a large bulky tube less practical to transport. In many other parts of Southeast Asia, students often travel via motorcycle which also does not allow for transporting of a large bulky tube.

To be low-cost, we need to carefully choose the objective size and structural materials. In contrast with commercial ultralight or truss Dobsonians, the telescope-in-a-box has a much smaller objective diameter. This is particularly important since the cost of a Dobsonian is primarily driven by its objective diameter.

More importantly, the telescope-in-a-box must have a rich set of educational opportunities in the classroom and in the field. That means the telescope design must be sufficiently capable on its own, while at the same time provide sufficient educational opportunities through its design. A good example of how this is accomplished is the gallileoscope[3], which is a simple refractor that is designed to be taken apart and assembled in class, with ample opportunities to demonstrate optical principles[4]. While the gallileoscope was originally developed for the price point of 30 USD and does not include a tripod, the telescope-in-a-box that we have built costs about 250 USD which includes a simple Dobsonian mount.

2. The Tubeless Telescope-in-a-box prototypes

In the course of its design and construction, we have constructed two prototypes for the telescope-in-a-box. Prototype 1 has a 200mm f/6 primary mirror, with a focal length of 1200mm and was constructed to demonstrate the tubeless design with off-the-shelf mirror cells and focuser. In addition, the carrying case was also designed to double up as the azimuth base and rocker box. However, that meant the carrying case needed to be stronger and hence heavier. In addition, the primary mirror cell was an off-the-shelf part that was excessively heavy, but extremely sturdy. The secondary support pole used a 30mm aluminium T-slot extrusion, which is readily available and sturdy, but also very heavy. The final carrying weight of prototype 1 is 21 kg.

Prototype 2 was constructed as an attempt to improve on the basic Newtonian design in addition to the tubeless design. It has a 112.5 mm f/8 primary mirror with a focal length of 900mm (taken from an existing Newtonian telescope) and was constructed to be lightweight and compact. In its collapsed form, the main parts can be packed in a small plastic box (excluding the poles and base). In particular, prototype 2 uses custom 3D printed parts (printed on a modified Flashforge Creator Pro) including the mirror cells and focuser and has a much larger altitude bearing.

In addition, prototype 2 was designed to be assembled without any special tools; It only requires a simple screwdriver for secondary collimation. To make the final design lightweight, we chose not to use the carrying case as a structural component, while the secondary support is a pair of lightweight wooden (paulownia) poles. The final carrying weight of prototype 2 is less than 3kg.

2.1. *Design Decisions*

In the course of the design and construction process, we note that the use of custom-designed parts allow for a closer examination of the physical principles underlying telescope design, and potentially allows for the teaching of iterative design methods. For example, the focuser in prototype 2 is a threaded rotating helical focuser which took multiple tries to perfect, because of manufacturing tolerance issues. To solve this, the final design used a compliant split thread that would hold the focuser tube, while at the same time be tolerant of less than ideal manufacturing precision. Similar concepts can be taught, and the choice of focuser design can also be a potential lesson plan.

In addition, the design of the mirror cells provides an opportunity to discuss the concept of kinematic couplings and degrees of freedom, while the design decisions that go into the secondary pole provide an opportunity to examine beam deflection, centre of mass and material selection. This is in contrast to the use of off-the-shelf parts such as mirror cells and focusers which lock the user in to a tried-and-tested design paradigm.

The use of custom parts for prototype 2 did not result in any significant additional costs beyond 3D printing, with the final bill of materials for prototype 2 being less than USD 200. Here, the single most expensive part is the mirror set (a new mirror set with similar specifications costs USD 90; http://www.e-scopes.cc/), although it is certainly possible for amateurs to grind their own primary mirror. Amateur telescope makers have made telescopes with little more than plywood, cardboard and carpentry skills.

For prototype 2 much time was spent on multiple design iterations. While this may seem to be a disadvantage, the design iterations provide a hands-on experience on how the parts fit together, and the physical principles that go into the design, from

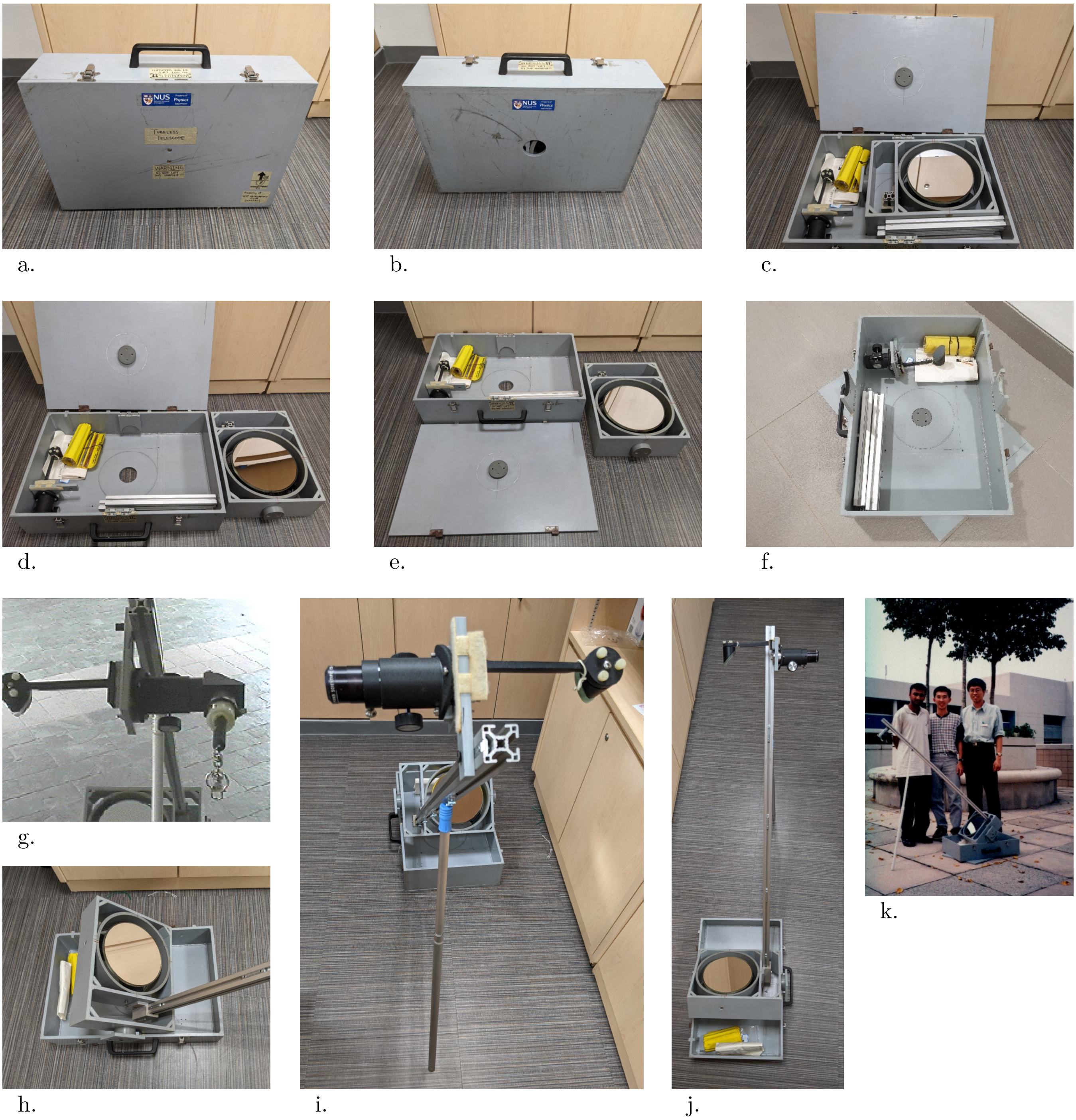

Fig. 1. Tubeless Telescope in a box prototype 1. a. Front view. b. Back view (note the round hole). c. Contents of the box with accessories. d. The primary mirror box taken out. e. The separated cover (note the round peg). f. The box is placed on the cover and can be rotated about the peg. g. The secondary mirror section with custom laser collimator. h. The primary mirror section. i. The fully assembled telescope. j. The fully assembled telescope with the secondary support pole. k. One of the authors with 2 students Arun Vythilingam and Lim Sin Hoe at Nanyang Polytechnic.

which we can construct lesson plans. Therefore instead of starting from scratch, the telescope-in-a-box design and lesson plans provide a starting point for experimentation and authentic learning. More importantly, by providing a set of pre-constructed parts, the plans to make replacement spares and the design principles that go behind these parts, we set the tone that telescopes are accessible and open to

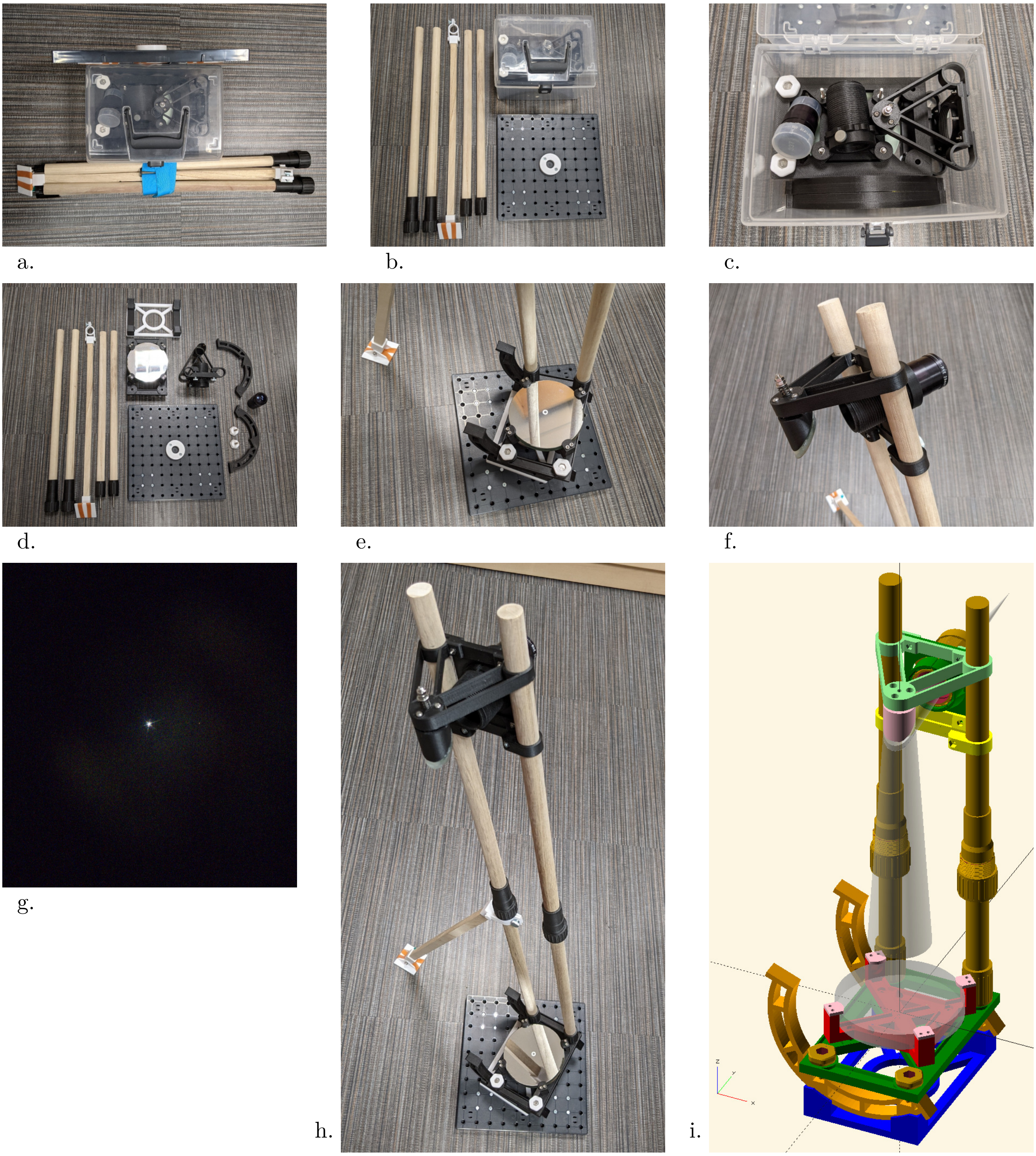

Fig. 2. Tubeless Telescope in a box prototype 2. a. Packed bundle. b. All loose parts. c. Contents of the box with accessories. d. All parts. e. The primary mirror section and support foot. f. The secondary mirror section with eyepiece. g. Afocal image of Sirius through prototype 2 (Edmund Optics 28mm RKE and Google Pixel 3a). h. The fully assembled telescope with the secondary support pole. i. CAD render of the telescope design.

experimentation, rather than expensive equipment that needs to be carefully controlled and rationed.

3. First light and Deployment

Prototype 1 was first tested on the Moon where it gave a reasonably clear view. It was subsequently deployed on a number of observing field trips.

Prototype 2 was tested on Sirius with a 28mm Edmund Optics RKE eyepiece, and performed reasonably well for a very lightweight telescope. Vibrations damped out reasonably fast in about 5 seconds. Diffraction spikes were somewhat strong and 6-pointed because of the secondary support design.

The only problem with the design was balance, where the secondary side was too heavy. This meant that the lowest practical altitude was about 40 degrees without additional support. Adding a counterweight and replacing the 3d-printed lower section with one machined from aluminium or steel would help this problem by lowering the centre-of-mass.

4. Future Work

The telescope-in-a-box concept is not complete in its current form. Many of the design decisions that go into building these prototypes can be written into lesson plans that demonstrate one or more physics or engineering concepts in telescope instrumentation. In addition, these concepts can also be used to redesign the basic structure to accommodate telescope mirrors of different sizes and we plan for subsequent models to have 200mm f/5 and 150mm f/5 mirrors, and to utilise not just 3D printing but also allow for parts to be made in a traditional machine shop. This will allow for parts made of stronger materials such as aluminium, steel or wood. We plan to make the design open source, with multiple design options depending on available fabrication capabilities.

Finally, as a stretch goal, we see the possibility of adding automatic tracking capabilities through the addition of two stepper motors and a microcontroller, which will open up further lesson plans and turn the telescope-in-a-box into a fully-featured telescope system.

Appendix

Specifications of prototype 1 (as built)

Box Dimensions
390 mm × 585 mm × 150 mm
Central Hub Diameter
60 mm
Fully Extended Height
1560 mm
Box Material
Rigid PVC
Total Carrying Weight
21 kg
Estimated Cost
USD 750

Specifications of prototype 2 (as built)

Box Dimensions
223 mm × 175 mm × 150 mm
(excluding poles/base)
Central Hub Diameter
50 mm
Fully Extended Height
1000 mm
Telescope Structural Material
Carbon-fibre impregnated PETG
Total Carrying Weight
3 kg
Estimated Cost
USD 200

Prototype 2 Bill of Materials (as built)

- 1× Mirror set: USD 90.00 (http://www.e-scopes.cc/)
- 1 kg PETG-CF filament: USD 35.00 (Aliexpress)
- 4× 20mm dia×450mm wood pole: USD 6.00
- 1× 15mm sq.×450mm wood pole: USD 1.50
- 1× Base Plate: USD 1.50
- 1× Carrying Case: USD 1.50
- Fasteners and springs: USD 20.00 (*est.*)
    - 4× M6×30mm hex head screw
    - 4× M6 nut
    - 6× M4×40mm hex head screw
    - 2× M4×10mm thumbscrew
    - 8× M4 nut
    - 1× M4 washer
    - 3× 5mm ID×20mm spring
    - 3× M3×20mm philips head screw
    - 4× M3×15mm philips head screw
    - 2× M3×10mm thumbscrew
    - 9× M3 nut
    - 6× 3.5mm × 12mm woodscrew

References

1. I. C. Jacobi, H. J. Newberg, R. A. F. Darren Broder, A. J. Milano, A. T. W. Lee A. Newberg and D. C. B. Whittet, *Astronomy Education Review* **7**, 66 (2008).

2. A. Yang, S. C. C. Ng, Q. Leong, M. H. Tan, P. Agarwal, Z. Ong, H. W. Ang and A. H. Chan, *The Physics Educator* **01**, p. 1950004 (2019).
3. S. M. Pompea, R. N. Pfisterer, S. Ellis, D. N. Arion, R. T. Fienberg and T. C. Smith, Optical and system engineering in the development of a high-quality student telescope kit, in *Modeling, Systems Engineering, and Project Management for Astronomy IV*, eds. G. Z. Angeli and P. Dierickx (SPIE, 2010).
4. S. M. Pompea, R. T. Sparks, C. E. Walker and E. F. C. Dokter, Optics education through the Arizona Galileoscope program, in *Optics Education and Outreach II*, ed. G. G. Gregory (SPIE, 2012).