Feasibility and Design for the Simplex Electronic Telescope

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Charge:

A feasibility check and design hints are wanted for the proposed Simplex Electronic Telescope (SET). The telescope is based on a conventional reflector telescope, with a concave mirror at the end of a tube focusing a distant image. The mirror might be of parabolic or spherical cross-section.

Instead of a secondary mirror, the SET has an electronic image sensor (EIS, typically a CCD or CMOS device) as used in digital cameras or video cameras. Input from the EIS is fed directly to form the image on a screen (such as an LCD). For most applications, the image will be displayed upright. The screen may be behind the telescope tube or may be separate, according to the application.

The telescope could be usable for astronomical viewing and/or closer viewing, as for a security system. For a convenient hand instrument, the screen may be of similar size to the telescope tube end, and the device could be held by a handle as on a megaphone.

Focusing can be achieved by sliding the EIS up or down in the ray path. Magnification can be by 'digital zoom', just presenting an enlarged version of part of the image.

To combat excessive pixilation with digital zoom, it may be possible to use EIS devices with higher resolution of detector sites towards the centre.

Discussion:

The SET described is a simple version of a modern observatory telescope, in which no one observes directly, but rather manipulates data generated by an electronic image sensor at the focal position of the telescope. These professional sensors are of sophisticated design and enormous (now measured in Gigapixels), but in essence are identical to the CCD image sensor in your cell phone or webcam.

It is commonplace for amateur astronomers to use what is essentially a 1 MPixel webcam mounted in their telescope instead of an eyepiece. Such a camera cannot be set for time exposures, and hence is only useful for observing the moon and planets, as well as earthly scenes. This sort of camera, if mass produced, would cost less than $10 to manufacture.

The approach used to image astronomical objects with this class of camera is generally to take a large number of exposures (these cameras usually work at 15-30 frames per second), and then add the frames together using software. It is possible to obtain reasonably good planetary images on a steady night by simply adding the images together continuously in a computer, using an algorithm that eventually 'forgets' the earlier images, but the best performance comes from carefully aligning details on successive frames (or on selected high-quality frames) to build up an image. This process can't be done in real time with amateur capabilities.

Just to give an idea of scale, most webcam CCD chips have an active area about 4 mm across. If you fit one with a 'standard' 3" f/15 refractor, pointing it accurately is a tricky business. Aimed at the Moon, the image would show about 1/3 of the moon's width. On a 32" screen, Jupiter would appear to be about 2.5 inches across. The theoretical limit of resolution would be just about equal to the distance between pixels.

What is the next step – what do you do better? The answer is time exposures and cooled CCDs, if you want a SET that can view any deep-sky objects. Unfortunately, using time exposures removes some of the immediacy of pointing the scope and seeing, say, the Ring Nebula M27. On the other hand, the view can be quite exciting, and the anticipation builds as an image slowly emerges out of apparently random noise on a monitor.

The best compromise here for an astronomical SET is an uncooled CCD camera capable of time exposures. Such sensors appear in those digital cameras which are capable of taking time exposures. As they are uncooled, exposures in excess of about a minute are not very useful (high thermal noise), but they will allow just about anything you can see by eye to show up on a screen within 10-30 seconds. A problem is that the SET has to remain still during the exposure. This increases the mechanical complexity, weight, and portability. The cost of such a camera for this application could be a lot less than a good digital camera – maybe less than $50 to manufacture.

Another approach to visual observation involves direct observation through the telescope using an eyepiece integrated with an image intensifier. These devices are not common, as they are expensive ($2K and up), and have definite limitations. They will not display on a screen unless you install a camera instead of the eyepiece. Used with one's eye, these devices extend the sensitivity of the telescope by about 2 magnitudes while at the same time slightly reducing the contrast of the observed image (which is usually from a greenish phosphor). Although from an astronomical point of view this is probably offers the user experience closest to that which you want, the cost and somewhat unnatural appearance of the image suggest that image intensifiers are not best for the SET.

Handheld SET

For a handheld device, I think you are essentially describing a modified digital camera. It doesn't much matter if the optical system is reflecting or refracting, save that you might want more optical zoom capability than would be easy to build into a reflector using a ccd camera as a secondary mirror.

As to the structure and optical design of the SET, I don't see that anything particularly tricky has to be done. The easiest implementation would be very much like a compact digital camera. Make a camera body just the size of the desired display (probably an OLED display say 4-8 inches diagonal, once those are reasonably priced), mount a time exposure capable CCD sensor inside, mount a wide-range zoom lens (perhaps even with macro capability, so you also get a low-power microscope), and have fun.

Let's look at a specific example. Take a 1/2.5" standard CCD sensor, as are commonly used in compact digital cameras. This has an imaging area of 5.76mmx4.29mm – about 1/6 the size of old fashioned 35mm film – and may have 5-8 Mpixels, each of which is about 2-3 microns in size. Then put on a wide range zoom lens. The Kodak Z990 1773662 has a 30x zoom lens – 5-150mm focal length, and the camera sells for $200 street price. Although the camera took a beating in reviews, its lens system did quite well.

At the widest zoom, the diagonal field of view would be about 80° wide, while at 150mm focal length the diagonal field of view would be about 2.5° wide. The effective diameter of the lens at the longest setting is about 30mm, the size of a small pair of binoculars. The moon would be 1/5 the size of the screen diagonal – say around an inch on the viewer screen. Jupiter would be about a millimeter – probably too small to see a disk. One could give up wide angle capability for more magnification if astronomy was the main goal of the SET system. (At some point, it would become too high in optical power to hold by hand, although this problem would be reduced by conventional anti-shake technology.) In macro mode the effective magnification on the screen would be somewhere around 30-50X, I believe.

Mounted SET

For a larger device, mounted temporarily or permanently on a secure and vibration-free support, we are now talking about a special device that mounts on a special telescope. It doesn't really matter if the telescope is reflecting or refracting, save that for a given size the reflecting optics will usually cost much less.

The device will be a ccd imager with a zoom lens that acts as a variable power 'eyepiece' for the ccd chip (the technique is called eyepiece projection). If the SET is intended for amateur or professional astronomy, the ccd will be able to take time exposures, and might be cooled in a high-end package to reduce thermal noise. Devices similar to this part of the SET currently run $500-1K for introductory amateur systems (a few Mpixels).

The easiest approach from an optical point of view is to mount the imager device as if it were a Cassegrain secondary mirror on the optical axis of a parabolic mirror, save that it would be positioned at the focus of the mirror. A small motorized rack or screw device could adjust the focus over a wide range, so that the SET could be used on close-up terrestrial targets. The obscuration of the mirror by the ccd device would be minimal, as the complete imager could easily be built within a 1" diameter device, even with cooling.

Imperfect SET optics

It is in the area of optically flawed optics where interesting possibilities enter. You suggested a spherical primary, or a Herschlean (tilted Newtonian) telescope. These give relatively poor images, and short of using special and difficult to construct correction lenses with the ccd imager, would not work well at all.

However, there is an interesting possibility. Imagine you use a short focus spherical primary, so that you are dealing with strong spherical aberration, or even a short focus paraboloid, giving a lot of off-axis coma. In the absence of corrective optics, it is still possible to obtain a good image, although not quite in real time as yet. If you send light from a point source through an optical system, it is distorted to some extent by the optics. This is not like atmospheric distortion, which can be corrected using active optics, but is static in nature – the same point of light in the same direction always forms the same distorted image.

The distorted light image is called the convolution of the original pristine point of light with the optical transfer function of the optical system. In nearly all cases the result is a blurry or smeared image, in which information about the incoming light has been lost.

The trick is, the loss of information, while real, isn't as great as you think on observing the image. If the image source is a single point of light, you can observe that the image is just that you expect from a point of light, and can mathematically perform a transformation that replaces the faulty image with that of a nearly perfect point of light. This transformation is called deconvolution – a procedure in which the known flaws of an optical system are removed from an image it produced, to the extent allowed by information entropy.

Deconvolution works amazingly well, depending on the magnitude and character of the errors in the optical system. Generally, errors that take points to more or less centered distributions of light will be better corrected than those which are smeared. This suggests that spherical aberration may be more correctable than coma. Also, one of the easiest targets for deconvolution is an image that you know is largely made up of points of light, such as star fields.

However, the process of deconvolution is computationally intense. I am not currently aware of a non-professional image processing system that can deconvolute a megapixel size image in real-time. Despite this, it may be another approach toward the construction of cheaper large telescopes.