Digital imaging trends in consumer astronomical photography

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Abstract

Since the launch of the Hubble Space Telescope there has been widespread popular interest in astronomical imaging. A further series of events, most notably the recent Deep Impact mission have served to fuel further interest in this. In parallel with this there have been a number of events and trends that have increased interest in astronomical photography outside of professional astronomy. Advances in imaging hardware have made a significant contribution over the past few years. This paper will examine these advances with examples of state of the art imaging systems. The paper will conclude with some potential trends for the future.

Introduction

The past 15 years have seen major changes in consumer astronomical photography. New telescope designs have promoted explosive growth in the availability and performance of astronomical telescopes for the consumer market. This is now a significant market with annual global sales to the advanced consumer market (telescope apertures of ≥ 150mm) estimated in 2004 to be $40 million[1]. These technologies have now developed to an extent that they are also ready for use in other imaging applications.

The combination of these telescopes and new electronic imaging devices allows amateur astronomers to now produce some stunning images[2]. These technologies, beginning with the telescopes, are summarised in this paper.

Telescopes

The layman's impression of a telescope is a unit that looks something like Figure 1, a refractor that can be traced back to the original design attributed to Lippershey and used by Galileo.

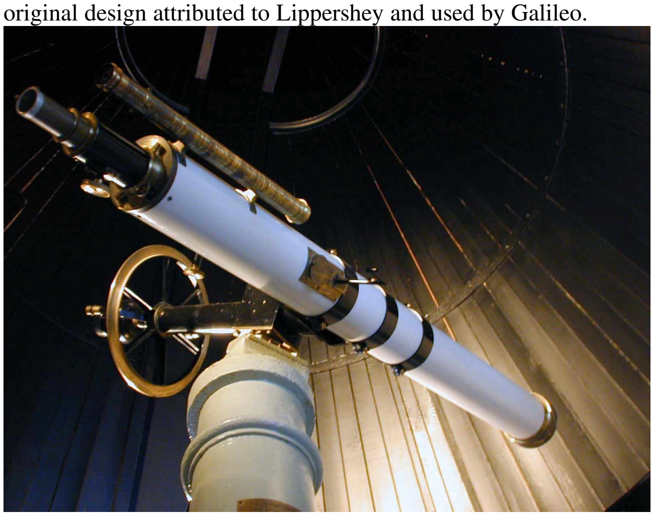

Figure 1 The 1850 Cooke refractor at the Yorkshire Museum, York, UK.

Of similar ancestry is a reflecting design attributed to Isaac Newton. Reflecting telescopes generally employ a mirror made to a parabolic figure. This has the advantage that all rays parallel with the optical axis converge to the focal point, irrespective of the position they are incident on the mirror. However, the manufacture of parabolic mirrors of the required tolerance is difficult and expensive and they are prone to substantial geometric aberration in the form of coma towards the edge of the field. Moreover, the coma is more pronounced as the focal length of the mirror is reduced so large focal lengths and hence long telescopes were required. Coma causes the image to be degraded away from the central field of view, and the usable field size for photography is limited, especially in short-focus instruments.

The above problems are overcome by using a spherical figure for the primary mirror. Spherical mirrors are easier and cheaper to manufacture and do not suffer from coma, making them very suitable for imaging purposes. However, they do suffer from spherical aberration – rays parallel with the optical axis no longer converge to a common focal point. As a result corrector plates in the form of an aspheric lens the full size of the telescope aperture are required.

The first of this type was produced by Bernard Schmidt in 1930, combining reflective and refractive elements to give a catadioptric telescope. The aim was to produce a compact design without the chromatic aberrations of the refractor and the geometric aberrations of the reflector combined with a large field of view. The Schmidt design with the essentially defect-free image plane was a great improvement for astro-photography and as a result was the basis for a number of highly successful professional telescopes. However, because the magnitude of the mirror spherical aberration varies inversely with the cube of focal length it was still difficult to achieve a compact unit and the need for a full aperture corrector plate kept costs high. In addition the image produced was not flat and the design required photographic plates curved to the image plane[3], which in the early days required the use of special products coated onto very thin glass[4].

Further designs followed, notably the Maksutov-Cassegrain and the Ritchey – Chrétien. The Ritchey – Chrétien is corrected for coma and spherical aberration, giving sharp images across a wider field of view than other previous designs and is used in many recent professional telescopes. The most well known variant of this design is the Hubble Space Telescope.

These designs do still have their difficulties. Maksutov-Cassegrains are expensive to manufacture in large sizes and Ritchey-Chretien telescopes are prone to diffraction effects from a spider-mounted central obstruction, reducing the Strehl ratio of the optics and degrading the image[5]. The challenge is now to reduce this image degradation and produce compact designs to low cost. Whilst this is undoubtedly an attribute for the consumer market there are potential applications for such a design in the military and scientific market segments too.

An example of these new designs applied to astronomical telescopes is the Cape Newise[6], illustrated in Figure 2.

Figure 2 A 200mm aperture Newise reflector telescope

The Newise is an example of a design hopping applications as it is derivative from an earlier design made for terrestrial applications[7]. This has found application in bird watching and military and scientific imaging.

The optical configuration of the Newise is illustrated in Figure 3 from the patent literature[6].

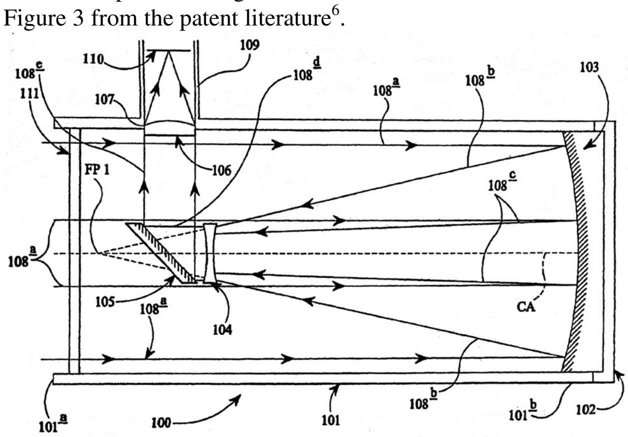

Figure 3 Optical configuration of a Newise reflection telescope

This design has a spherical primary mirror (103) and a flat secondary mirror (105) with a negative lens (104) in between in axial alignment. This negative lens allows the use of a short focal length primary mirror (and hence a compact design) whilst giving a focal length large enough for adequate magnification to be achieved. The light is then passed to a positive lens at the side of the telescope tube which focuses the light rays onto an eye piece or imaging device. The telescope reduces or substantially eliminates spherical aberration and can be configured to have a focal ratio significantly greater than the focal ratio of the primary mirror. The telescope produces an image which is substantially diffraction limited and a flat field of view which is therefore excellent for electronic imaging.

A further but very important attribute of this design is that the central obstruction caused by the optical elements 104 and 105 (Figure 3) is small compared to other designs. As described above this increases the Strehl ratio of the optics and improves image quality. The small size of this obstruction can be seen in Figure 6.

Refractor design

Whilst these modern designs are capable of producing high image quality in low cost compact reflecting telescopes there is a similar need for improvements in refracting systems for astronomy and other applications too, such as camera lenses, military optics and periscope systems.

Traditional refractors such as those illustrated in Figure 1 need a front (objective) lens that is multi-element to correct for the dispersion of glass. This tends to make them heavy and expensive. An alternative solution is again to use a multi-element objective lens but with significant air spacing between the elements. This type of design is known as a Dialyte[8]. The design has a number of advantages in terms of cost and weight. First, the front element can be made as a singlet, significantly decreasing cost. The later elements, being well spaced from the single-element objectives can be much smaller and hence lighter and lower cost. This also has the advantage that the weight distribution of the optics is much better.

However, whilst the original Dialyte design corrects for longitudinal colour the issue of lateral colour correction remained unresolved. Refinements to the design[9] aimed to resolve this but resulted in very long optical trains.

Further work on the concept has increased the useable field of view and produce folded, compact optics[10]. The design has also been proved in practice to produce the largest refractor in amateur hands, a 30 inch aperture unit made by John Wall in the UK.

Image recording

Astronomy and photography have been closely linked since the earliest days. Louis Daguerre is said to have taken the first astronomical photograph in 1839, a picture of the moon.[11]. Dry glass plate photographic systems[4] produced a large number of major astronomical discoveries as long exposures enabled the recording of fainter objects. These techniques were for many years outside of the capabilities of all but the most enthusiastic and capable amateur[3] and amateur imaging was done predominantly by sketches. However, the ready availability of good consumer 35mm SLR cameras over the past 40 years, and the advances in telescope design resulting in the ready availability of telescopes with a flat image field enabled excellent results to be achieved by coupling these cameras onto telescopes[12]. Here the telescope optics act as a large telephoto lens, focusing the image on the camera plane by replacing the eyepiece lens illustrated in Figure 2 by a camera adapter as shown in Figure 4.

Figure 4 A SLR camera on a Newise reflector telescope

The use of Digital SLRs was an obvious progression from film cameras and is another example of technology crossing applications. Of particular note here is the Canon EOS 20Da, a Digital SLR camera made specifically for astronomical imaging and presented at NIP21 last year[13]. Compared to other digital imaging solutions that are described below the digital SLR has the advantage of being a complete unit in itself, not requiring an external computer and power supply to function. This can be a major advantage in remote outdoor locations.

There are 2 factors that are driving the use of Digital SLR units in this application. Firstly, as described above new telescope designs are appearing that combine compactness with large flat fields suitable for electronic imaging. Secondly the price / performance ratio of both telescopes and imaging systems continues to move in more favourable directions. With entry level cameras now above the 5 MPixel level[14] and telescopes with the flat field ability to fill these chips the combination is capable of recording some very high quality imagery.

The market for imaging systems for astro photography is significant. The annual value of astronomical accessories of which imaging devices are becoming a significant fraction was estimated in 2004 to be $20 million[1]. The growth of interest in astro imaging looks set to greatly inflate this figure in coming years.

Bespoke CCD systems for astronomy look set to be an interesting and potentially lucrative niche for devices to cross from scientific imaging applications into consumer astronomical photography. Their potential for providing the highest image quality gives the serious enthusiast the migration path from digital SLR cameras. Both colour and monochrome systems are being used, the latter for multiple imaging using optical filters. These can be either traditional RGB sets or specific wavelengths selected to give high contrast images on emission objects such as nebulae. For urban areas where light and air pollution can serve to reduce image contrast light and haze reduction filters are also available.

Adaptive optics systems are now appearing in this market. They are limited to first-order tip-tilt systems which compensates for gross image motion due to the atmosphere and are usually employed on bright objects such as planets. However, they are also finding use with the long exposures needed for faint objects.

At the other end of the cost spectrum we have a similar thing happening with low cost web cameras finding their way into astro-photography. These cameras have the advantage of being very small and can be purchased in a housing that allows them to be placed in the eyepiece tube of the telescope, as illustrated in Figure 5. Although this type of unit has a low entry cost there is a need for a laptop computer to drive the unit.

Figure 5 A webcam fitted in the eyepiece tube

In between these 2 we have the use of surveillance video cameras and compact digital "snapshot" cameras making similar transitions.

There is an ongoing debate within the industry on the relative attributes of CCD and CMOS imaging technology. Current opinion within consumer astro photography circles resides on the side of CCD technology but advances in CMOS technology[13] could challenge this. However, the current state of CCD technology[15], together with a growing market in astronomical accessories has resulted in a new market niche – the bespoke imaging camera mentioned above.

Telescope mounts

With the magnifications employed in astronomical photography and the exposure times used to acquire images (sometimes over 1 hour per colour) a stable mount is essential. As astronomical objects also move with the rotation of the earth some form of accurate motor drive is also essential. Systems such as that illustrated in Figure 6 combine stability and portability. Modern manufacturing techniques have also made them available at reasonable cost. Systems are now available for electronic control to allow the telescope to be automatically guided to any object in a star atlas or locked to an object in the image field, facilitating the use of even longer exposures whilst reducing image movement.

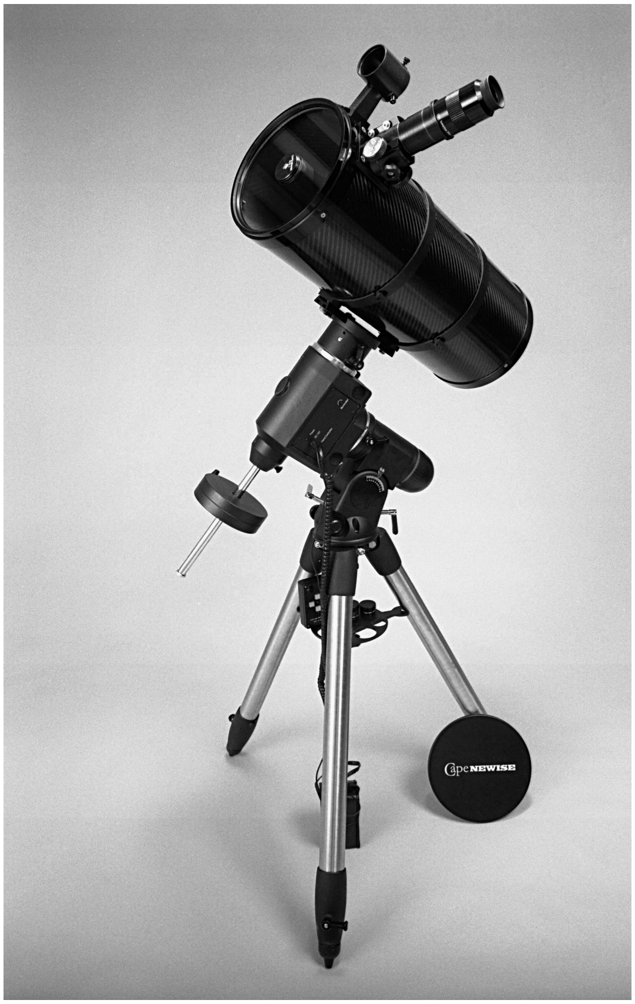

Figure 6 A Newise telescope on a commercial mount

The future

The future for these technologies and markets looks good. Bigger and better telescopes fitted with higher performance imaging systems will be in the hands of amateurs, schools and institutions as price / performance shifts more into their favour.

Finally, one further exciting development is the International Space Station Amateur Telescope. The goal of this project is an astronomical telescope mounted on the International Space Station and operated by amateur astronomers. The system is currently under development with robotic ground based telescopes at the Arizona Sky Village.

Conclusions

Compact telescope optical design has progressed over the last few years with greatly enhanced price / performance ratios. These optical designs are now capable of much enhanced imaging performance and will very likely see applications outside of astronomy in the near future.

As a result of the flat image fields of these designs there is now a significant market in electronic imaging devices for consumer astronomical photography. We will very likely see new entrants and technologies in this market with success waiting for those with knowledge of the market and application.

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Author Biography

Alan received his BSc in chemistry followed by a PhD in instrumentation from Manchester University in 1982 and began work as an Image Physicist with ILFORD Imaging. After a number of technical support and Sales & Marketing roles his final role was Technical Services Manager at the head office in the UK, covering both traditional silver image and emerging ink jet technologies. In 2004 he left to become an independent consultant on optics and non-impact printing. He is a member of the IS&T and the Institute of Physics.

Peter is a telescope designer and Managing Director of Cape Instruments Ltd. He is the brains behind the Evolution, Newise and refractor designs illustrated in this paper.