SOME CONTEMPLATED IMPROVEMENTS TO THE PROTOTYPE LIXISCOPE

Dr. Lo I Yin
Solar Activity Branch, Laboratory
for Astronomy and Solar Physics
Goddard Space Flight Center

The evaluation of the prototype Lixiscope, constructed entirely from easily available components, shows that many improvements can and should be made. The purpose of this paper is to describe some contemplated improvements. These can be divided roughly into two categories: those which are well within existing technology, and thus can be implemented immediately; and those which are more at the state-of-the-art level, and which are directly related to applications in X-ray and gamma ray imaging in astronomy.

OBVIOUS IMPROVEMENTS WITHIN EXISTING TECHNOLOGY

Size

As many people have pointed out, it is highly desirable to have a larger format microchannel plate (MCP) intensifier without sacrificing the portability or the maneuverability of the Lixiscope. A larger size will help significantly in terms of orientation and the ease of examination. The present prototype uses a 25-mm diameter MCP. The next available size of the MCP is 40 mm in diameter. Unfortunately we have not been able to obtain one, although they do exist. An alternative way to achieve a larger format is to use tapered fiber optics. For example, if 2:1 tapered fiber optics are used with the 25-mm MCP intensifier, 2:1 in the front and 1:2 in the back, this effectively gives a 50-mm diameter Lixiscope. Given the present X-ray phosphor and MCP intensifier, there will be little or no degradation in resolution as a consequence of the additional tapered fiber optics. This is because the limiting resolution of 4 line pairs per mm (lp/mm) of the prototype is governed by the rare-earth phosphor converter. The inherent resolution of the MCP image intensifier for visible light is about 30 lp/mm. Therefore, as long as the fiber size in the large-diameter end of the tapered fiber optics remains much smaller than the resolution limit of the phosphor converter and the resolution in the minified end is still well within the capability of the MCP intensifier, there will be little or no loss in resolution. These conditions can be easily met by the available tapered fiber optics. The slight loss in intensity due to additional transmission through the fiber optics can be compensated for by the intensifier gain. Note that there will be no loss in detection efficiency because this is still governed by the same phosphor converter. The resultant object-to-image ratio in this case is again 1:1. In those instances where magnified images may be advantageous, they can also be achieved through tapered fiber optics instead of lenses.

Non-Inverted Image

The image from the inverter MCP intensifier tube used in the prototype is a source of inconvenience and mild annoyance. This can be eliminated by the use of a "wafer" MCP intensifier which is currently available and does not have an electrostatic inverter lens. Furthermore, the wafer tube decreases the thickness of the entire device to about 1.5 cm, making it more compact. However, wafer tubes in general have lower gain than inverter tubes, so that the resultant image is much dimmer at the same input flux. This can be remedied by the method described in the next paragraph. A 180° twisted fiber optics plate can also be attached to an inverter tube to provide a non-inverted image.

Brightness

At present, an automatic brightness control (ABC) circuit is included in the standard power supply of night-vision MCP intensifiers. This protective feedback circuit senses the output phosphor current such that when it reaches a predetermined value the gain of the MCP is decreased by reducing its operating voltage, thereby preventing possible tube damage due to accidental overexposure. When a radioactive source of a given activity is used as the X-ray source there is no danger of overexposure to the intensifier. Readjusting the ABC, or disabling it, will allow the intensifier to operate at maximum gain and possibly brighter output. However, the maximum gain of standard night-vision MCP intensifiers is limited by the length-to-diameter ratio (L/D) of the microchannels (about 40:1), and the onset of ion-feedback noise and oscillations. In this regard, the electrostatic inverter lens serves as an ion trap, and thus enables the inverter tube to achieve higher gain than that of wafer tubes with the same L/D MCP. This maximum gain still may be insufficient to provide enough brightness for operation near the quantum limit of a low X-ray flux. To remedy this situation, but keeping also within the confines of readily available technology, one could use two wafer tubes in cascade, or one MCP wafer tube followed by a diode intensifier, to achieve higher gain and brighter images. This is especially attractive in the case of two wafer tubes in cascade because the overall thickness of about 3 cm still provides for a very compact device.

Film and Camera

The prototype uses an off-the-shelf Polaroid CU-5 close-up camera and ASA 3000 instant processing film. Clearly there are other alternatives, especially if one increases the output brightness. Improvements are possible in such areas as the proper matching of phosphor output wave length and film sensitivity, optimal choice of film characteristics, and photometer equipped miniature camera. In this regard, it is worthwhile to point out that MCP image intensifiers can also be switched on and off electronically. The intensifier can be switched "off" by applying a negative bias to the MCP input relative to the photocathode, thereby preventing the photoelectrons from entering the MCP. Such electronically-gated operation is available, and can be used to eliminate the mechanical shutter of the camera.

Safety

As demonstrated with a Geiger-counter survey of the prototype Lixiscope, with proper design the radiation exposure to the radiologist can be made insignificantly small, i.e. not above background level. However, because the Lixiscope is compact, portable, and easy to use, it can also be easily overused on a subject. Therefore, it is extremely important to establish safe operating guidelines. It may also be helpful to install digital timers, both interval and integral (accumulative), which are triggered by the switch that unshields the radioactive source or turns on the X-ray tube. In this manner, not only are exposure records kept, but the timers may also serve as a psychological deterrent against overuse.

Another aspect unique to the geometry of the Lixiscope is the short distance between the "point" source and the detector. Because of this short distance, the dose rate to the object increases quickly (i.e. l/r^2) as it is moved from the detector toward the source. For example, for a 50-mCi ^{125}I source, while the dose rate at 5 cm from the source is about 0.3 mR/sec, it can reach almost 20 mR/sec a few mm from the source. Therefore, it is desirable to place a mechanical stop in front of the source to establish a minimum distance beyond which the object cannot travel. At a minimum distance of 2 cm, for the same 50-mCi ^{125}I source, the maximum dose rate is now about 2 mR/sec.

Photocathode

In the prototype, the Lanex Regular X-ray phosphor is coupled to an S-25 photocathode simply because these two components were readily available. S-25 is desirable for night vision because of its broad sensitivity extending into the infrared region. It is not especially efficient in the 550 nm and ultra-violet emission region of the Lanex screen, nor for most of the X-ray and gamma-ray scintillators. A proper choice of photocathode, such as S-20, would improve both the detection efficiency and the signal-to-noise ratio.

Decay Time of Output Phosphor

Because the Lixiscope is primarily a fluoroscopic device and the integration time of the eye is about 0.2 sec, it is advantageous to have an output phosphor with long decay time to improve the visual image quality. Of course the decay time should not be increased at the expense of output-phosphor efficiency, nor should it be so long that it interferes with the observation of the dynamic motion of interest.

STATE-OF-THE-ART IMPROVEMENTS

Gain and Gain Distribution

The most important difference between the Lixiscope and conventional X-ray fluoroscopy using diode intensifiers is that of electron gain. In conventional diode intensifiers, the photoelectron image, resulting from the conversion of the original X-ray image into a visible-light image which then impinges on the photocathode, is converted back to an intensified visible-light image by the acceleration of the photoelectrons onto an output phosphor—either with or without minification. In this approach, the number of photoelectrons remains constant; only their kinetic energy is greatly increased by the accelerating potential. In placing a MCP between the photocathode and the output phosphor, the number of photoelectrons is first multiplied, and then their kinetic energy is increased by an accelerating potential to the output phosphor. In the prototype Lixiscope, using an inverter night-vision intensifier tube loaned by the Night Vision Laboratories, the electron gain of the MCP (L/D=40) is about 10^4. As mentioned earlier, wafer tubes with the same L/D MCP usually have lower gain because of ion-feedback problems. Perhaps a little explanation about ion-feedback is in order.

In an MCP with straight microchannels, as the electron gain is increased by increasing the applied potential between input and output, a certain point is reached where the electron cloud near the output end of the microchannels can cause ionization of the residual gas in the tube. The gas ions, travelling in the opposite direction (ion-feedback), may strike the photocathode or the channel wall near the input end. In either case, if an ion liberates an electron, another electron-multiplication cascade can be initiated following the original event. Such ion-feedback pulses increase noise, decrease tube lifetime, and cause runaway oscillations. However, ion-feedback can be eliminated to a large extent by using two or more MCP's having slanted microchannels in series in a "chevron" or "Z" configuration, or, more recently, by using a MCP with curved microchannels. Either way, the ions are prevented from reaching the input end of the microchannels near the photocathode. Now the feedback pulses can no longer achieve the same gain as the true events. In addition, with the elimination of ion-feedback, it becomes possible to greatly increase the achievable gain of MCP's.

However, when the gain of a curved MCP or chevron MCP's is pushed to 10^6 or 10^7 range, another phenomenon, charge saturation, occurs. That is, for microchannels of a given diameter and resistivity with single-electron inputs, a stage is reached where the 10^6 or 10^7 electrons near the output end, within the pulse duration of about a nsec, significantly decrease the electric field at the output end such that no more multiplication is possible. At this stage, all input electrons will achieve essentially the same gain, and gain saturation results.

Prior to gain saturation, such as in the normal operation of the nightvision MCP intensifier of our prototype, there is a large range or distribution of gains for single-electron inputs. Although one speaks of an average gain of, say 10^4, the distribution in gain is actually very wide and exponential in shape. Such large fluctuations in gain for pulses within a single microchannel, compounded with the fluctuations among microchannels, can give rise to contrast degradation and poor signal-to-noise ratios. Using a curved MCP or chevron MCP's in the gain-saturated mode, not only is the average gain increased by several orders of magnitude thus resulting in brighter images, but the gain distribution becomes narrow and peaked in shape. Such peaked gain distributions significantly reduce the gain variance in a single microchannel as well as among microchannels, and consequently improve the image quality. Furthermore, the high gain of 10^6 to 10^7, together with the saturated gain distribution, make it easy to operate the MCP in the pulse-counting mode. This is the mode of operation which GSFC intends to use for X-ray and gamma-ray astronomy.

It should be pointed out that MCP characteristics such as ion feedback, gain distribution, gain saturation, and pulse counting of single-electron inputs are well known and have been studied by many investigators.

For the investigation of possible use of the Lixiscope idea in X-ray and gamma-ray astronomy, GSFC has obtained, once again through the courtesy of the U.S. Army Night Vision Laboratories, an intensifier tube fabricated by Varo Electron Devices which contains an experimental curved MCP provided by Galileo Electron Optics Corp. Figure 1 shows the pulse-height, or gain, distribution of this experimental tube for single-electron inputs. The average gain for single electrons is 1×10^6 in this case, with a full-width at half-maximum spread of less than 50%.

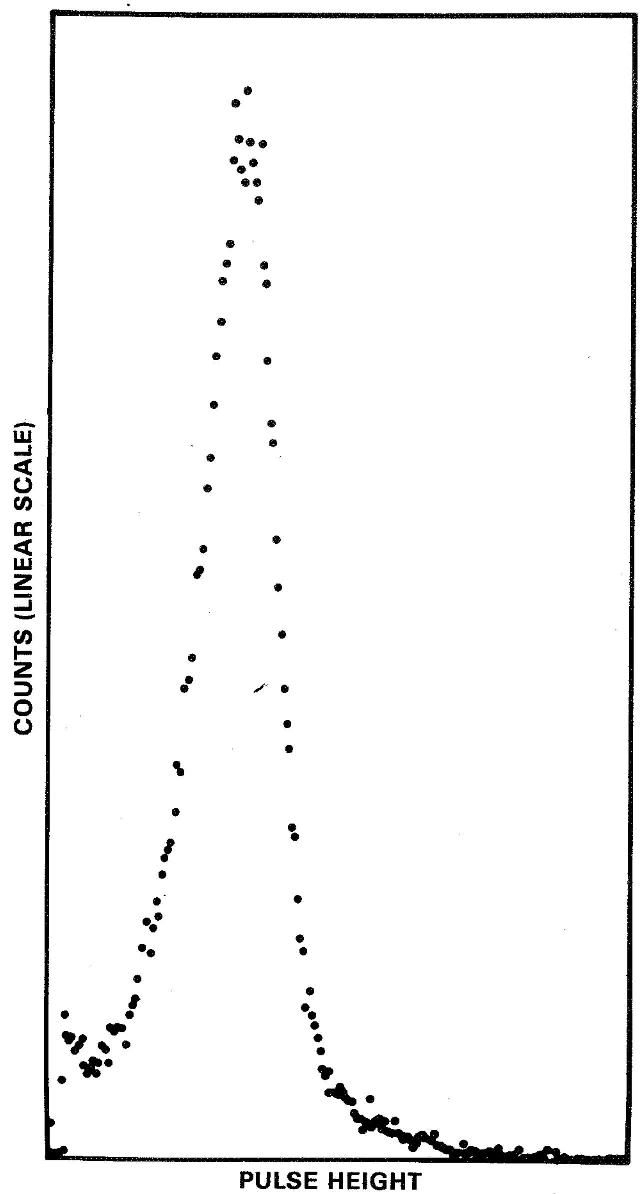

Figure 1. Pulse height (gain) distribution of the experimental curved-MCP intensifier tube with single-electron inputs.

With this experimental tube, and using a thin (about 60 μm) evaporated CsI scintillator, we have found that it is possible to achieve simultaneous imaging and single-photon counting of ^{125}I and ^{241}Am X-rays. Using a thick (0.6 cm) CsI(Tl) crystal scintillator and a variety of gamma-ray sources having energies from 30 keV to about 1 MeV, our results indicate coarse energy resolution as well. These are indeed the characteristics looked for in X-ray and gamma-ray astronomy. On the other hand, it is important to note that once simultaneous imaging and single-photon counting is achieved, we have also reached far below the quantum limit of fluoroscopy, whatever that limit may be.

X-Ray Gamma-Ray Scintillators

If one can pulse count each absorbed X-ray or gamma-ray photon in the scintillator, it is clear that the limit of information retrieval has been reached. Further increase in information content can only be achieved by improving the detection efficiency of the scintillator. In this regard, one is faced with the conflicting requirements of high quantum detection efficiency which demands a thick scintillator, and high spatial resolution with low lateral light spread which demands a thin scintillator. Activated CsI is an attractive choice for several reasons. First, it is more efficient than rare-earth phosphors at higher X-ray energies. Secondly, it has a fast decay time of about a μsec which is ideally suited for pulse-counting circuitry. Thirdly, there are commercial capabilities in depositing, or growing, activated CsI such that it has light-guiding properties in the longitudinal direction, with minimum spread in the lateral direction.

Collimators

The prototype Lixiscope uses a "point" radioactive source. For the purpose of imaging extended or spatially distributed sources, such as those encountered in radioisotope-intake studies, focusing or parallel collimators can be used in front of the scintillator. Alternatively, a pin hole, or multiple pin holes in conjunction with deconvolution instrumentation, can also be used to image extended sources. As is well known, collimators can also be used to reject scattered radiation.

Portable X-Ray Tubes

Nature provides only a limited choice of radioactive sources with the desired energy spectra, lifetimes, and specific activities. To be truly versatile, it is desirable to have an X-ray tube with continuously variable energy and intensity. The high gain of the MCP intensifiers makes it possible to use very low power. Furthermore, the X-ray tube can be operated in the pulsed mode with pulse rates of say, 20 to 30 per sec. Using these criteria, it is within the realm of present technology to design and fabricate a miniaturized, fully portable, battery-operated, rechargeable X-ray tube. Such an X-ray tube would extend the usefulness of the Lixiscope to much wider ranges of industrial and medical applications.