Miniature Camera Modules For Visualizing Micro Invasive Surgery

By Martin Wäny, CEO AWAIBA HOLDING SA, Yverdon Switzerland

The miniaturization of camera modules allows visualization inside the body with ever smaller incisions. These miniature digital camera modules — hardly bigger than a grain of salt — enable novel medical tools, where visualization is possible for the first time and where previous procedures had to be done completely blind. In this article, AWAIBA, a reputed leader in miniature camera modules as small as 500 mm side length, provides an overview of these miniaturized cameras and explores potential new applications for the technology.

Introduction

Imaging and small size digital camera modules have become ubiquitous. Only few years ago, a digital camera recorder was still a considerable investment and its size and weight were a potential encumbrance. Today, however, the presence of digital cameras everywhere seems self-evident. Smartphones usually implement more than one camera, and game consoles are gearing up to several modules to combine video, still digital, and 3D interaction with the total gaming experience. This inflation of cameras was only possible by their miniaturization (both in size and in cost). As with many innovations in the electronics business, the engine behind driving down size, costs, and increasing performance comes from the semiconductor manufacturing industry. The industry follows the famous Moore's Law, which predicts that the size of transistors will halve and, consequently, performance of integrated semiconductor devices will double every one and a half years. The results of this race to ever smaller and better-performing digital processors and memory chips applied to digital imaging make it possible to realize image sensors with pixels as small as 1 mm. This is mainly driven by the consumer electronics industry where 1.1 mm pixel size is in mass production, and some companies work on 0.9 mm pixels already.

The standard digital mobile device camera module, however, still measures between 4 to 5 mm in each dimension. This is due to the system cost optimization realized by combining many image pre-processing functions on the image sensor itself and from utilizing plastic-injected components for lens holders and overall housing.

At AWAIBA, we have taken on the task to skim down from this approach everything not imperatively needed for the bare imaging task and to combine the sensor technology with optics technology and an assembly that will not add to the overall module size. This resulted in the smallest ever digital camera module presented in 2008, with a side length of 500 mm x 500 mm and a build height of only 0.9 mm. The module included a wide angle lens, or the NanEye off-the-shelf product family, with a 1 mm x 1 mm footprint, a 1.4 mm build height, and several integrated optics variations to provide images at 62k pixels in full digital format. This article will provide a short outline of the technologies required in manufacturing this type of camera module and present some of the current and possible future applications.

Figure 1: NanEye 2D 1 mm size camera module

Technology

In order to minimize the footprint of a digital camera module, it was first necessary to rethink the digital image sensor itself. Current standard digital image sensors for digital imaging — such as in mobile phones, webcams, or other devices — embed a number of functionalities and follow architectures suitable for scaling up to several Mega pixels resolution. This results in only part of the chip surface being used for the actual pixel matrix, and a considerable peripheral area used for column parallel AD (analogue digital) converters, low power charge pumps, automatic exposure control, possibly color reconstruction algorithms, and mobile processor interfaces. Such features do not only require chip area in the periphery of the matrix, but also require many times the external components for voltage stabilization in the vicinity of the image sensor. When optimizing the technology and architecture for minimal module size, AWAIBA removed every feature that was not absolutely mandatory for the chip, and redesigned the others to achieve a chip periphery below 90 mm on each side of the matrix — even with sub 1 mm chip size. On a chip with 700 mm side length, this leaves less than 0.2 mm^2 for all peripheral electronics (In a digital mobile phone imager, the digital interface controller may consume this area on its own). Further, the chip architecture was optimized to avoid the need for any passive components located close to the chip, such as decoupling capacitors, allowing for the camera heads to run up to 3 m cable length and reliably transmit the digital output signals without the need of coaxial shielding cables. It also prevented the loss of image quality due to electromagnetic interference.

However, the size-optimized image sensor by itself is not enough to build minimal-sized camera modules. In order to permit the chip packaging on such a small footprint, the electrical connection to the imager is made by chip scale packaging technology, which provides the electrical contact from the electronics to the outer world by “drilling” tiny via holes through the silicon and connecting form solder balls on the back side to the active electronics on the front side. This technology is also known as TSV (for True Silicon Via), and it permits the overall device and package size to retain the exact outline of the image sensor circuit. In addition, TSV does not require extra area for bond wires or connections over the device sides.

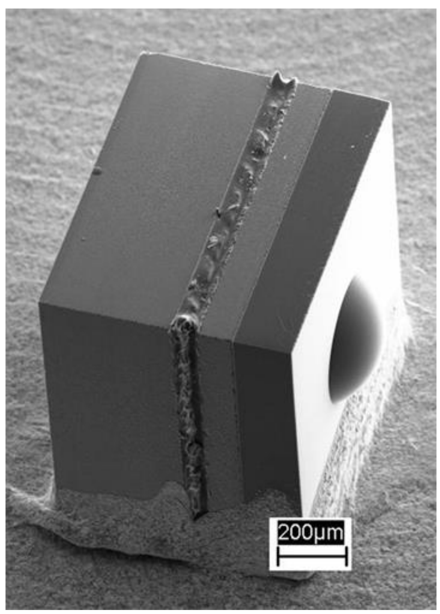

Figure 2: NanEye 1mm size camera module with wafer level lens in SEM photograph

Finally, any hobby photographer knows that the greatest camera body is worth less without an adequate lens. However, when things shrink to the 1 mm scale and below, optics and especially the precise placement of optics becomes exceptionally challenging. To mitigate this at AWAIBA, we employed technologies coming from optical and mechanical micro systems manufacturing (such as the processes used to make acceleration and tilt sensors in a tablet) to manufacture lenses by etching the lenses out of quartz glass wafers and assembling the full wafer stack on the CMOS image sensor wafers. This approach is a very unique technology developed by AWAIBA and several research institutes for the first time. However, besides the miniaturization, it also provides a great economy of scale. When slicing up pizza-sized wafer stacks to 1mm or smaller camera modules, several thousand cameras result from one single wafer stack, thus allowing for incredibly low cost at high volumes.

Applications

First applications of this technology address known endoscopic procedures. On the one hand, reusable flexible endoscopes where the miniaturized camera modules replace the fiber optic image bundles increase the resolution and image quality and enable more flexible scopes that can take narrower turns, flexing into places and viewing angles not available previously. The first realized applications of reusable scopes with such miniaturized digital camera modules were urethoscopes and laryngoscopes. Compared to fiber image bundles, the chip on the tip camera modules can provide about 2 to 3 times higher resolution (e.g. with the NanEye_2D standard camera module, 62k pixels instead of a 15k to 20k fiber optic bundle), which leads to a strong honeycomb image artifact besides the limited resolution.

Disposable devices are possible with the technology due to its possible lower cost at high volume compared to fiber bundles. The big driver behind disposable endoscopes is patient safety. Flexible endoscopes are extremely difficult to clean reliably, and patient cross infection is an ever-increasing concern. Further, the cost of sterilization and equipment management incurred with reusable equipment can be avoided by using disposable devices, which are available from the consumable stock.

The availability of moderate cost disposable camera modules further allows the implementation of visualization for devices operated blind before, such as guide wires or electro surgical probes. Nathaniel Group has integrated the NanEye_2D camera modules in a 2 mm outer diameter visualization module together with two illumination fibers for a disposable probe for a manufacturer of bronchoscopy devices designed for onsite biopsy analysis for lung cancer. Other customers have integrated the modules in disposable electro surgical probes used in cardiac surgery For video click here.

Figure 3: Image taken by NanEye_2D camera module inside lung (courtesy Nathaniel)

Further drivers of disposable endoscopy devices made possible by miniature digital camera modules such as the NanEye family camera heads include the move of endoscopic procedures out of the operation theater to the doctor's practice. A 1 mm size camera module can be integrated in a surgical needle and may be applied by punctuation rather than by an incision, which greatly reduces the complexity and cost of the procedure.

Future Outlook

In the future, we see plain visualization tasks evolving down two paths. On the one hand, visualization will provide even higher resolution with the same module size. Coming form an industry following Moore's law, however, this is a "no brainer" statement. Secondly, with approximately the same resolution, modules with ever-decreasing sizes will be available. AWAIBA has already shown that 500 mm x 500 mm is possible, and our studies show that even 300 mm x 300 mm would be possible provided there is an application that will finance the upfront development cost.

Besides 2D visualization, the small size optical modules allow a third dimension in the visualization by including two more adjacent cameras. The Technical University of Munich has embedded a stereo version of the NanEye camera module with a surgical robot. By embedding the module, they managed to teach the robot how to tie knots with the surgical string and needle used in micro invasive robot chirurgic procedures. For this, AWAIBA has developed a pseudo random pattern projector and combined two perfectly aligned and parallel NanEye_2D camera modules using the full wafer manufacturing approach (See Figure 4). The pseudo random pattern projector permits the mapping of the contrast picture from the two cameras and creates a 3D point cloud that allows the robot to find the 3D position of the needle and string and perform the knot tying autonomously (Try to do this with one eye closed, and you can get an impression of how challenging the task is. Then imagine having to teach this to a machine, working inside your stomach).

Figure 4 NanEye Stereo module for 3D vision

Less complicated uses of the 3D capability of these camera modules include the simple, repeatable measurement of dimensions (e.g. when assessing if a lesion is growing or stable, which is a frequent task in women's health context). When doing this by endoscopy, knowing the exact distance between the scope and the tissue is mandatory.

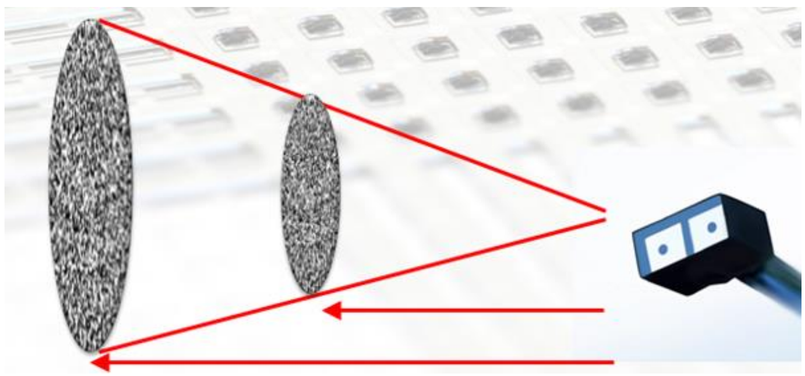

Figure 5: Principle picture of distance measurement with the NanEye Stereo module and a pseudo random pattern projector