The Hybrid Autocollimator

Upgrading a century-old instrument technology to lead the way for modern intricate laser & optical measurements

Oren Aharon and Itai Vishnia

Source: Artem Oleshko / 123RF.com

The concept of autocollimation as an optical instrument was conceived about a century ago for accurate, non-contact measurements of angles. Since it was invented, it has developed a long history of being used in alignment of angles and optical elements. Recent novel photonics development has created a need for alignment and measurement of optics and lasers – the new hybrid technology does exactly that.

For better understanding of the technology, an optical schematic illustration of the classical autocollimator is shown in Fig. 1. The system has a light source followed by a projection reticle. The light source is an LED (usually 670 nm, IR versions were recently introduced), and after passing through the beam splitter, it enters the objective lens where it is collimated prior to exiting the instrument. Collimation means that the projected reticle is exactly one focal length away from the main surface of the objective lens. The projected collimated light is back reflected by a mirror, or other high-quality reflective surface, and is captured by the objective lens. The returned image appears in sharp focus on the high-quality CCD detector. Due to the high sensitivity of the detector, even a very faint back reflection will be captured and displayed.

Deviation of the mirror by an amount *a* causes deviation from the original line of sight by an amount of 2*a*. Assuming the amount of deviation of the reflective surface and the focal length is denoted by *f*, then the mirrors' deviation is determined by the relationship: $a = x / 2f$.

From this equation it is apparent that measuring mirror angular deviation is independent of the distance between the instrument and the reflecting surface.

Deviations in azimuth and elevation can then be electronically determined and calculated by a computer. Furthermore, the results are then clearly displayed on its screen. Resolution down to 0.01 arcsec is achievable.

As a rule of thumb: the higher the *f*, the higher the resolution. As a result, the field of view is smaller and thus it is more difficult to acquire the reflected signal.

The electronic method offers the advantage of complete objectivity in data recording as well as a computer interface, unlike optical autocollima-

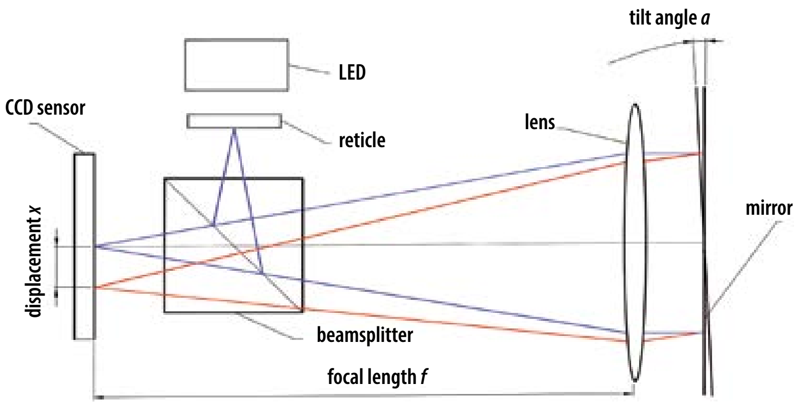


Fig. 1 Optical schematic illustration of classical autocollimator and telescope into one instrument (Source: Duma Optronics)

tors which are bulkier and less accurate.

In a telescopic application, where the telescope is calibrated to infinity, the angle of movement is $a = x / f$.

Novel hybrid electronic autocollimator

Recent technologies require many new measurements that could be performed by upgrading the fundamentals of autocollimation. This upgrade will expand the usability of the newly introduced hybrid autocollimator throughout the photonics industry. Measurements such as laser measurements, laser alignment, silicon wafer alignment, multi-laser measurements in parallel, VCSEL and inter-alignment between laser, optical axis and mechanical datum plane will be feasible. This is achieved by fusing the autocollimation concept with laser beam profiling and accurate mechanics. Measurements such as laser angle measurements, positioning, parallel characterization of multiple lasers and relative deviation between mechanical datum to laser systems are feasible. So implementing leading-edge technology into the autocollimation concept can add functionality and revive this century-old technology. Duma Optronics did just that, fusing together some exciting technologies into the existing electronic autocollimator. Features such as motorized focusing, built-in laser beam profiling, multiple laser beam characterization in parallel, multiple illumination wavelengths for crosshair and fast processing up to 1,000 fps have culminated in a totally new instrument. This instrument will serve new applications in laser production, alignment, car lidar, MEMS mirrors, optical fibers, measurement and characterization of VCSEL arrays (used for 3D face recognition) and many more.

A novel autofocusing electronic autocollimator was developed that is capable of repeatable motorized focusing at different distances. Progress in laser analyzing instrumentation development allows implementation of this technology into electronic autocollimation. Until recently, measurements of mirrors or the mechanical datum plane relative to a laser beam was a daunting task. The focusing feature with accurate line-of-sight retention allows angle and position measurements of mirrors as well as laser beams and laser beam collimation. Multiple new applications will be demonstrated such as the centering of wafers using lasers, the alignment and centering of mirrors, the alignment and centering of VCSEL laser arrays, etc.

Autocollimator technological improvement fundamentals

The concept of autocollimator improvement is based on several building blocks such as multisource illumination, an automatic focusing knob, a fast CMOS sensor, and a software upgrade to provide modern high-tech laser optical and mechanical application.

The use of multisensors integrated into one advanced autocollimator as an alternative to conventional usage of several measuring instruments to perform an intricate alignment or measurement solves many problems in day-to-day applications. The major upgrade is the unique combination of a laser beam profiler integrated into the autocollimator measuring capability.

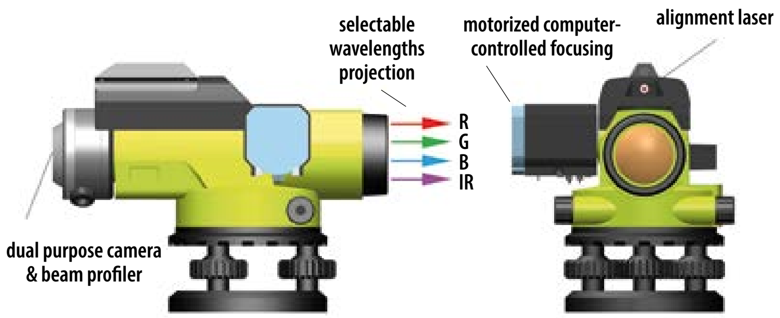


Fig. 2 Schematic illustration of hybrid technology including RGB+IR illumination and built-in motorized focusing (Source: Duma Optronics)

This is complemented by the unique motorized focusing of the autocollimator, which in turn forms a multi-wavelength autocollimator from visible to NIR and beyond. All the optical elements including multiwavelength sources are precision mounted and the entire instrument is rugged and stable, providing very accurate beam pointing and robustness for various applications. By maintaining the alignment of the beam profiling device with the autocollimator's line of sight, a new application field is available for integrating and aligning lasers with optical elements and telescopic sights. Moreover, by integrating multiple independent beam profiling measurements from one sensor, a leap forward is achieved for performing measurements of VCSEL arrays and their alignment to specific optical assemblies.

At first glance, the multitask autocollimator looks similar to its predecessor, but its sensory system has been greatly upgraded as follows:

- A dual-purpose camera sensitive from deep UV to NIR is used as an autocollimator sensor, as well as a beam profiler
- Multisource illumination will project a cross line with different colors to create multiple crosses, adaptable to specific needs
- The motorized, computer-controlled focusing will automatically adapt itself to compensate for the difference created by the projection of different wavelengths
- By flipping the software application, the autocollimator will transform itself into a beam profiling telescope, accepting various laser beams to be analyzed for direction and divergence
- Yet another functionality created by the software will enable accurate measurements of a laser's M^2 numbers
- The motorized focusing will allow the autocollimator to focus at pre-calibrated distances, controlled by software
- A built-in alignment laser will point the line of sight's direction in a clearly observable way, facilitating fast and accurate alignment.

In practice – hybrid electronic autocollimator

The range of applications for laser beams in conjunction with optical elements is extremely diverse in such areas as medical technology, semiconductors, the automotive industry, manufacturing equipment, mechanical alignment, face recognition, autonomous driving and more. The flexibility that this new hybrid automatic autocollimator offers will solve challenging development hurdles in an exceptionally wide range of applications. A list of typical applications is discussed below. However, new approaches are created where efficient and flexible implementations take advantage of the hybrid autocollimator.

The latest flagship cellphone devices will probably implement 3D sensing modules for face recognition. One of the most promising technologies, already incorporated in iPhones, is based on VCSEL technology, where multiple laser beams are directed at the user's face and picked up by a second camera to create a 3D recognition pattern (image p. 60).

Others, such as Samsung, Huawei and Sony, will also implement similar technologies. Some will go an additional step further by equipping both cameras – front and back. Moreover, the structured light and time of flight are great candidates to determine depths and 3D patterns with extreme precision for autonomous driving. From the measurement point of view, there is a need to check alignment between mechanical mounting surfaces or the lasing chip surface in each laser direction. This hybrid technology can fulfill this purpose, for example by measuring mechanical surfaces with the autocollimator features, and a laser's direction with the same instru-

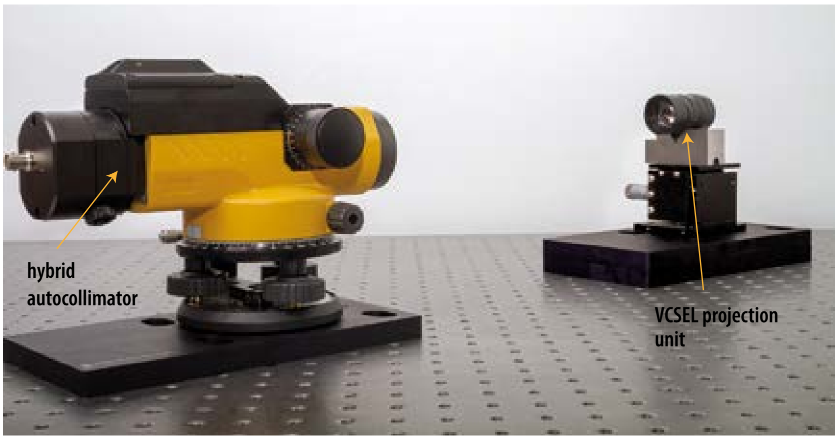
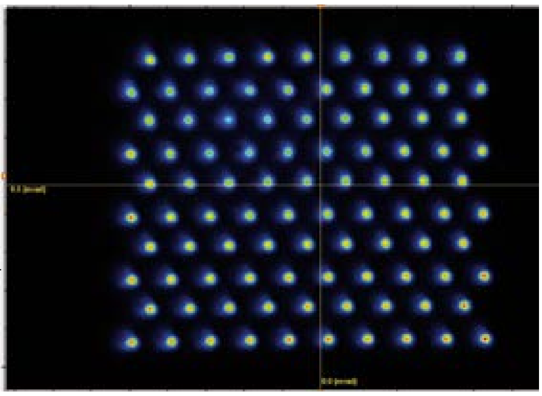
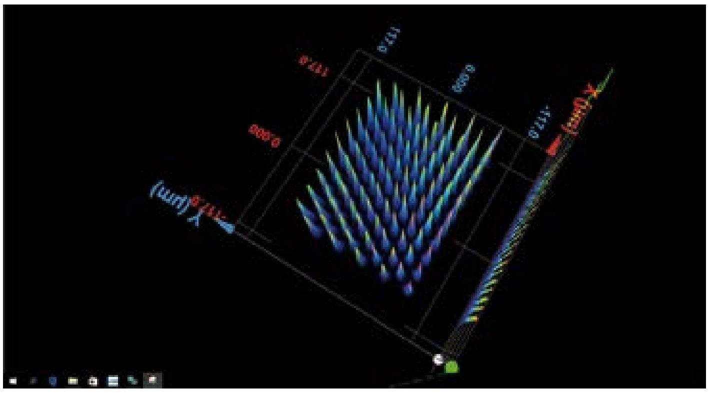


Fig. 3 Photographic layout of measuring application of collimated VCSEL array performance (Source: Duma Optronics)



Source: Duma Optronics

Fig. 4 A typical representation of a VCSEL array from the autocollimator software



Source: Duma Optronics

Fig. 5 3D screenshot from the hybrid autocollimator analyzing software representing the VCSEL and their relative power levels

ment in the appropriate measuring mode. Those relative measurements can be compared to each other and used in the QC of the system.

Traditional applications of autocollimators can also benefit from this new technology by combining laser technology in parallel with the autocollimation function – such as for centering, alignment and straightness measurements. The implementation of special technologies, such as PLX's lateral transfer hollow periscope LTHP, could also be used for boresighting and multiple line of sight alignment in conjunction with the autocollimator's hybrid technology.

Establishing multiple lines of sight

A modern test case will be to establish the accuracy of a VCSEL multi laser direction in space, along with establishing the reference mechanical line of sight. A setup performing this measurement is shown in Fig. 3.

Here we see the hybrid autocollimator where the optical VCSEL unit is positioned in such a way that lasers are projected towards the autocollimator input aperture. In this arrangement, we would like to perform two main measurements:

- To align the projector mechanical axis to the autocollimator's axis.
- To measure the relative position of the lasers to the mechanical axis and in between.

One can adjust the autocollimator to the mechanical axis by placing a mirror on top of the mechanical axis. Secondly, by using the hybrid autocollimator in the beam profiling mode, the VCSEL array position relative to mechanical axis can be determined, as well as the projection angles of each laser in the array.

In the following screenshots, the cross represents the mechanical axis as recorded by the autocollimator mode, with the VCSEL lasers projected to infinity by the optical element. We can clearly see the separation between various VCSEL sources, and measurements such as the beam size of each laser, its location, and relative power are available from a special software package. This will enable automatic assessment of the system's performance.

To guarantee eye safety, 3D reconstruction capability and the reliability of VCSEL (or other collimated) laser arrays, a lab measurement is essential and should be performed with high precision. A one-shot solution is offered by using the hybrid autocollimator technology, obsoleting such devices as optical goniometers and power meters. The profile of each laser on the array is easily examined, and comparative measurements of power and beam profile size are observable and can be analyzed. A spatial characterization of the VCSEL system is achieved by using this hybrid technology. The spatial regimes of a collimated VCSEL assembly, including emission patterns in the far field, are defined. This very accurate method rivals and surpasses goniometric measurements which are very tedious and time consuming. This is therefore an alternative to goniometric measurements and offers a solution suitable for mass production. However, for a specific application, it is advisable to precalibrate the measurement system for consistent and accurate results.

Conclusion

Hybrid technologies have the potential of satisfying the requirements of several technologies, such as alignment, the spatial characterization of lasers and beam profiling of multiple single emitters. This analysis process provides the angle-dependent spatial resolution patterns of light sources in respect to a mechanical datum plane, an adequate solution for the accurate and fast testing of VCSEL lasers. This specific application is given as an example due to the growth of VCSEL arrays applications, but many other intricate measurements involving lasers, mechanics, optical alignment and other technologies will become more generally available and relevant using this new technology.

DOI: 10.1002/phvs.202100001

Author

Oren Aharon has several decades of experience in the electro-optical field, including start-up initiations based on his patents. He founded Duma Optronics 25 years ago to offer advanced enabling technologies to industry. He owns thirty patents and graduated from Technion with a BSc in nuclear engineering and an MSc in industrial engineering. He has written numerous articles and served as a technical assistant to the Israeli Minister of Energy.

Further Author
Itai Vishnia, President & CEO, PLX Inc., Deer Park, NY, USA

Oren Aharon, Duma Optronics, Hazait 1st, Nesher 3675018, Israel; phone: +0506443001; e-mail: oren@duma.co.il; Web: www.duma-optronics.com